Communications System Architecture Development
For
Air Traffic Management & Aviation Weather Information Dissemination

Research Task Order 24

Subtask 4.8, Develop AWIN 2007 Architecture

(Task 7.0)

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Table of Contents

Table of Figures

Table of Tables

1 Executive Summary

1.1 Background

Aviation Weather Information (AWIN) and Weather Information Communications (WINCOMM) are elements of the National Aeronautics and Space Administration's (NASA's) Aviation Safety Program (AvSP). The AvSP will address the Office of Advanced Technology (OAT) goal of "reducing the aircraft accident rate by a factor of five within 10 years, and by a factor of 10 within 20 years." In 1997, an Aeronautics Safety Investment Strategy Team (ASIST) defined the objectives of AvSP in the following way:

> The team recognized that weather was a major contributing factor in aviation accidents and incidents. A key recommendation of the ASIST activity was for a significant effort in weather accident prevention. As a result, weather accident prevention (WxAP) has been incorporated as a key element of the AvSP. Furthermore, the ASIST weather team produced a prioritized list of investment areas under weather accident prevention. Weather data dissemination was considered the most critical and highest ranked priority on the list.[1]

The AvSP officially launches in fiscal year 2000. The specific activity (Task 7) addressed in this document is a pre-AvSP development effort. It is a sub-element under the Advanced Air Transportation Technologies (AATT) Research Task Order (RTO) 24, Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination.

1.2 Objectives

The objective of Task 7 is to develop a 2007 AWIN Architecture; i.e., to develop a communication system architecture (CSA) with the potential for implementation by 2007 that "can fulfill the goal of providing the collection and dissemination of aviation weather information and distribution of advanced weather products to the various aviation platform classes."[2]

1.3 Technical Approach

While the specific Task 7 objective addresses collection and dissemination of weather information, weather information and distribution must be viewed within the context of the overall National Airspace System (NAS) Architecture. For example, NASA's office of Aerospace Technologies has identified a technology objective stating:

> While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years.

The FAA's stated NAS weather architecture goal is to:

> Convert existing weather architecture—consisting of separate, stand-alone systems—to one where future weather systems are fully integrated into the NAS.

These statements clearly indicate the need to view the weather architecture in the full context of the NAS; in particular, the Air Traffic Management (ATM) component of the NAS. To provide that context, we

[1] Background from the "Communications System Architecture Development For Air Traffic Management Aviation Weather Information Dissemination" Request for Task Plan.
[2] "Communications System Architecture Development For Air Traffic Management Aviation Weather Information Dissemination" Request for Task Plan.

extracted user needs and high-level goals (Task 1) from a wide variety of sources, including other NASA and FAA programs, RTCA activities, and industry. From these needs and goals, we developed a consensus vision and concept of operations for the 2015 architecture (Task 5) to provide a "top down" perspective. We further refined the operational concept into nine communication technical concepts that formed our functional communication architecture. For AWIN, the functional communication architecture can be further simplified to those highlighted in Figure 1.3-1.

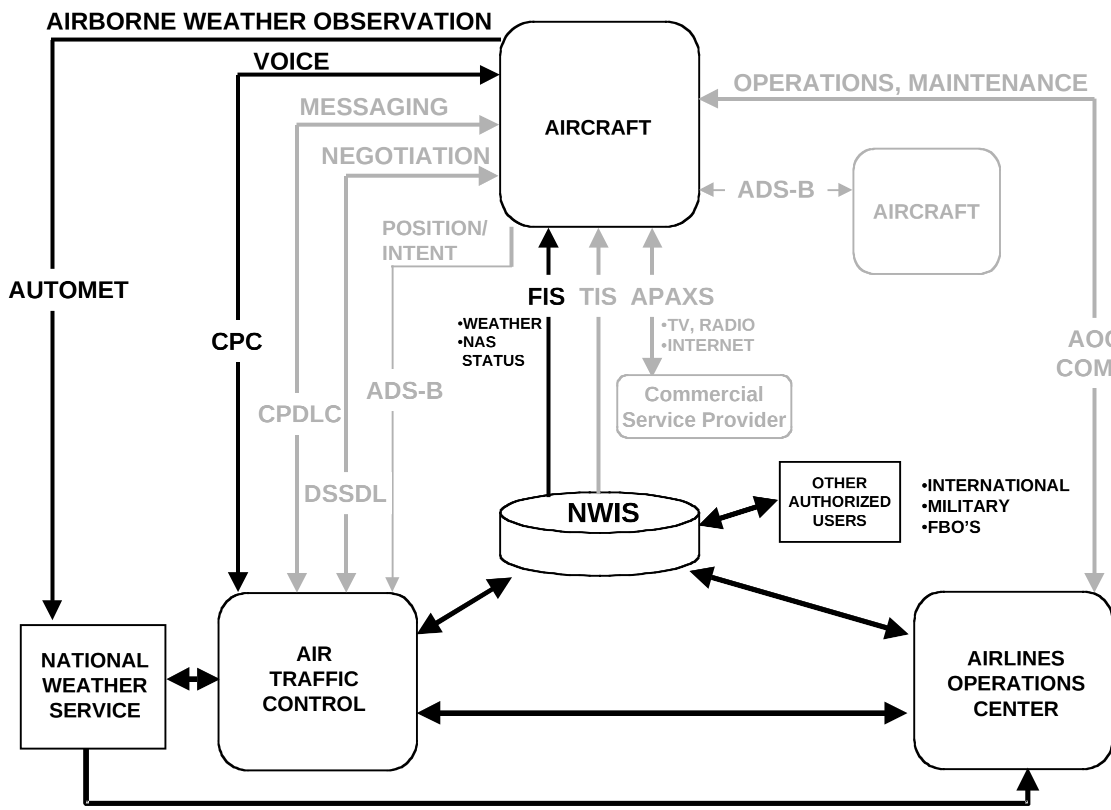

Figure 1.3-1. AWIN Functional Architecture

The functional communication architecture was used to formulate the physical architecture alternatives based on the results of our communication loading analysis (Section 4) and on our determination of communication link capabilities (Section 5). This process is illustrated in Figure 1.3-2.

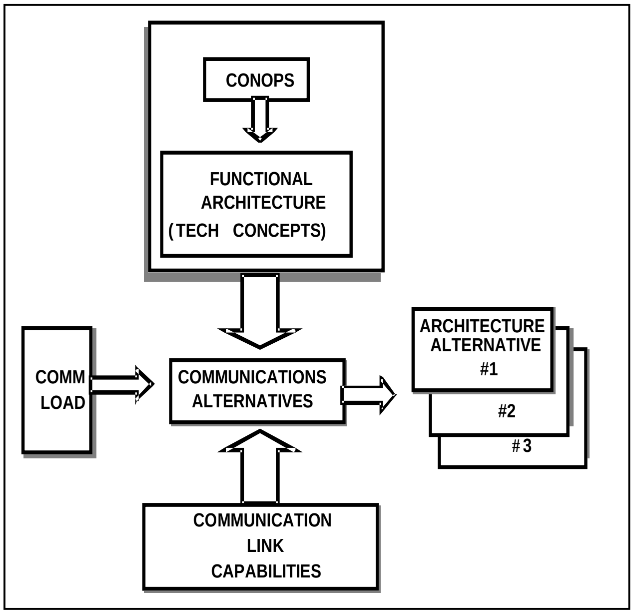

Figure 1.3-2. AWIN Architecture Alternative Development Method

1.4 Results of This Task

The results of this Task produced three alternative architectures as shown in the figure below

Category	Technical Concept	VDL-B	VDL-2/ATN	VHF-AM	UAT	SATCOM-2 way
1	FIS	■ ◇			○ ◇	△ ◇
4	CPC (voice)			■ △ ○ ◇		
8	AUTOMET		■ △ ○ ◇		◇	◇

◇ Technically Feasible
■ Alternative 1 - NAS Architecture
○ Alternative 2 – Terrestrial-Based
△ Alternative 3 – Space – Based

Figure 1.4-1. AWIN Architecture Alternative

As is shown in the table the only variations in the AWIN architecture alternatives are in the Flight Information Services (FIS) category. Given the communication link technologies that we determined could be available in 2007 and considering the 2015 architecture recommendation, we could not find a compelling reason to recommend a departure from the current NAS Architecture path for CPC or AUTOMET.

For FIS, our communication load analysis indicated that we can support regional data dissemination. However, we will exceed the capacity of any VHF data link for national broadcast in the 2007 time frame. The 2015 AATT communication architecture (Task 5 of this report) recommends that a national FIS data broadcast capability be provided using a broadband data link. (UAT or SATCOM).

This being the case, the choices are:

- Reduce the data requirements to fit within existing capabilities
- Create new compression or data packaging techniques that will support additional data with existing capabilities
- Develop multi-channel strategies that rely on avionics processing and storage capabilities to create the desired products from multiple data streams
- Move to a new communication system that supports the data requirements
- A hybrid of the above.

In summary, for the 2007 AWIN communication architecture, we conclude that the NAS Architecture provides the best solutions for controller-pilot voice communication (VHF-AM digital radios) and for AUTOMET (VDL-2). There are no acceptable solutions in this time frame for automated real-time delivery of hazardous weather information to the cockpit so this function must continue to be performed by the controller. Finally, for delivery of FIS data, the use of VDL-B will support regional dissemination of weather products and is sufficient for the 2007 time frame. However, national deployment of FIS should be accomplished through the implementation of a broadband data exchange capability. With this objective, further research should be conducted (as outlined in Tasks 5, 10, and 11) to determine whether a terrestrial-based, (UAT), space-based (SATCOM), or hybrid solution is most suitable.

2 Introduction

In 1995, NASA began the Advanced Air Transportation Technologies (AATT) initiative to support definition, research, and selected high-risk technology development. In fiscal year 2000, NASA will officially launch its Aviation Safety Program (AvSP). This report responds to a specific task (Develop AWIN 2007 Architectures), which is a pre-AvSP activity being conducted under AATT.

2.1 Overview of Task 7

The objective of Task 7 is to develop a 2007 AWIN Architecture; i.e., to develop a communication system architecture (CSA) with the potential for implementation by 2007 that can fulfill the goal of providing the collection and dissemination of aviation weather information and distribution of advanced weather products to the various aviation platform classes.

Task 7 is one of eleven related tasks in the AATT RTO 24, Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination. The relationships among these tasks are depicted in Figure 2.1-1. Task 5 develops the 2015 AATT Architecture, and Task 6 develops the 2007 AATT Architecture. Task 7 builds upon the communications system concepts developed in Task 4 and uses the definition of the 2015 CSA from Task 5 and requirements from Task 3 to define the recommended AWIN architecture. Elements of Task 9 define and determine what is achievable in 2007. The results of these tasks feed Tasks 8, 10, and 11.

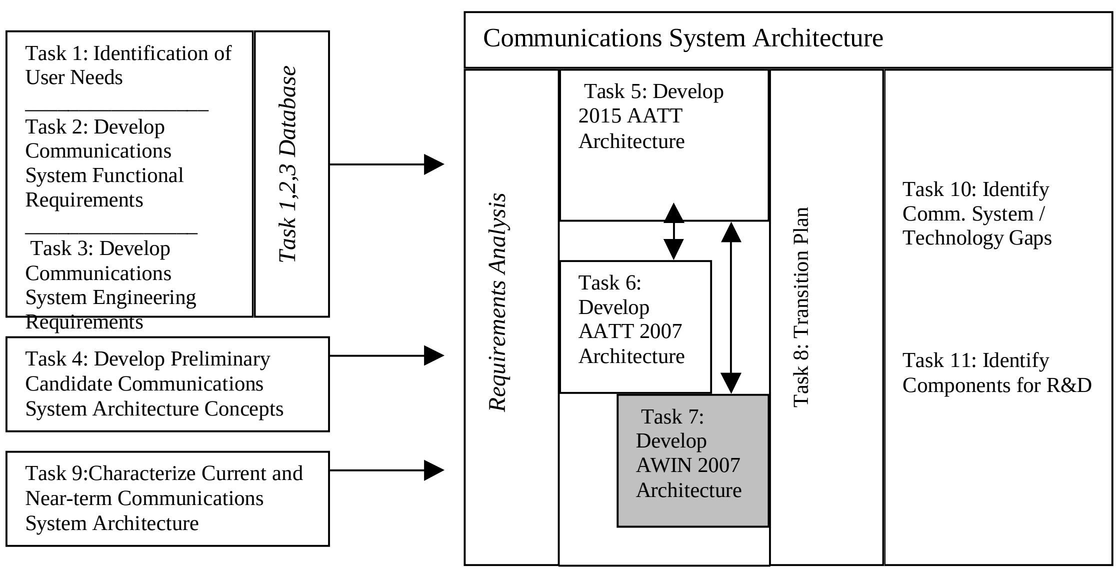

Figure 2.1-1. Relationship to Other Tasks

Task 7 began with a review of the relevant user needs and functional communications requirements collected in Tasks 1 and 2 of this RTO (RTO 24). This review was followed by the development of concepts of operation for 2007. Next, we analyzed the current CSA for weather products and the NAS Architecture for their ability to meet these needs. The Task 7 2007 AWIN Architecture was developed from this analysis and will be used to identify gaps for inclusion in Task 10.

To ensure weather data availability to meet the needs of all users of the Air Traffic Services, three classes of users were defined as follows:

- Class 1: Operators who are required to conform to FAR Part 91 only, such as low-end General Aviation (GA) operating normally up to 10,000 ft. This class includes operators of rotorcraft, gliders, and experimental craft and any other user desiring to operate in controlled airspace below 10,000 ft. The primary distinguishing factor of this class is that the aircraft are smaller and that the operators tend to make minimal avionics investments.

- Class 2: Operators who are required to conform to FAR Parts 91 and 135, such as air taxis and commuter aircraft. It is likely that high-end GA and business jets and any other users desiring to operate in controlled airspace will invest in the necessary avionics to be able to achieve the additional benefits.

- Class 3: Operators who are required to conform to FAR Parts 91 and 121, such as Commercial Transports. This class includes passenger and cargo aircraft and any other user desiring to operate in controlled airspace. These users will invest in the avionics necessary to achieve the additional benefits.

Based on the user needs and functional communications requirements presented in Tasks 1 and 2, the table below presents the high level goals and operational requirements to be met by the resulting communications architecture. These user goals and operational requirements have been grouped according to user class.

Table 2.1-1. User Goals and Operational Requirements

Class 1 User Goals	**Class 2 User Goals**	**Class 3 User Goals**
• Minimize/streamline interaction with ATM system • Make communications transparent and seamless for the pilot • Expand access to more airports in IMC conditions (High-end GA)	• Reduce limitations and delays caused by weather • Provide instrument approaches to more airports	• Expand the use of user preferred routes and trajectories • Increase airport capacity in IMC • Increase system predictability • Reduce weather related delays • Minimize time and path length for routing around hazardous weather
Class 1 Operational Requirements	**Class 2 Operational Requirements**	**Class 3 Operational Requirements**
Class 1 users require: • On demand weather • Weather at more sites • User friendly formats ("user friendly" is TBD but could include graphical, oriented to flight path, uncluttered, easy to interpret by solo pilot, etc.) • More real-time updates	Class 2 users require: • Weather at a greater number of sites • More real-time weather at remote sites	The Class 3 users, desiring a combination of preferred routes and increased capacity, require: • More precise weather information for routing • Weather information consistent with that seen by controllers and operations centers • Higher density grids at higher update rates to support decision support systems like CTAS and wake vortex prediction systems

The information above emphasizes a flow of information that generally is ground-to-air. However, the system will require more air-to-ground weather information to populate the higher density grids and enable near real-time updates.

2.2 Overview of the Document

Section 1 is an executive summary that provides a high-level synopsis of the document.

Section 2 introduces the task and provides background and context, including the relationship of Task 7 to other RTO 24 tasks.

Section 3 provides architecture concepts, characteristics, considerations and develops alternatives for the 2007 AWIN Architecture. It discusses the following topics in order:

- Our approach to developing architecture alternatives
- A summary of the 2015 AATT communication system architecture
- Development of the 2007 AWIN functional architecture
- Definition of the alternative architectures
- Technology gaps for the alternative architectures
- Transition path for the 2007 AWIN architecture

Section 4 presents the technical detail of the communication load analysis. It discusses the following topics in order:

- Inputs provided by earlier tasks
- The use of scenarios to organize the information
- Calculation methodology
- Numerical results of the message load calculations
- Implications and conclusions drawn from the numbers.

Section 5 provides the technical details of the individual communications links. For each communications link it presents:

- The link characteristics
- Significant points and tradeoffs considered in link selection.

3 Defining the 2007 AWIN Architecture

3.1 Introduction

The analysis leading to the definition of the 2007 AWIN communications architecture alternatives involved the three primary tasks shown in Figure 3.1-1: (1) defining an overall functional architecture to satisfy the desired services, (2) defining the information to be exchanged while providing the services (i.e., communication loading), and (3) identifying the enabling mechanisms (i.e. communication links) that are suitable for exchanging the information. Based on these tasks, we developed communications alternatives that were reflected in three distinct 2007 AWIN communications architecture alternatives and transition strategies. Note that the concepts presented in this section are not unique to Task 7 (2007 AWIN Architecture); rather, they apply equally well to Task 5 (2015 AATT Architecture) and Task 6 (2007 AATT Architecture).

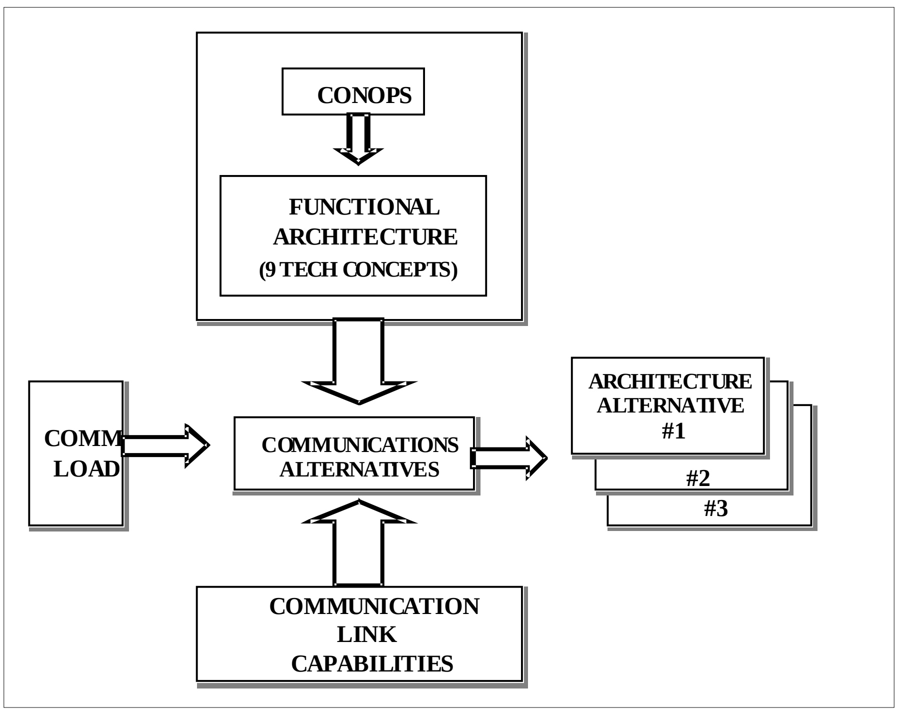

Figure 3.1-1. AWIN Architecture Alternative Development Method

Definition of the functional architecture first requires an understanding of the desires of the aviation community. To gain this understanding, we reviewed a wide range of user requirements as documented in Tasks 1, 2, and 3 and drew upon knowledge gained through our team's in-depth involvement in the development of the NAS Architecture. We organized our results by air traffic services and the functional capabilities into which the services logically divide, and then matched the message type requirements that were identified in Task 2 with this service/functional capability structure. The result was a *service-driven view of the message types* that had been identified. [Note that, for our purposes, a message type is a logical grouping of information that represents all data forms within that type, including raw data, commands, images, etc.]. We then focused these message types further with cross-cutting technical concepts derived from the CONOPS for the purpose of defining the functional architecture. Finally, by applying the appropriate enabling communication links to the functional architecture, we transformed it into the physical communications architecture. These relationships are illustrated in Figure 3.1-2.

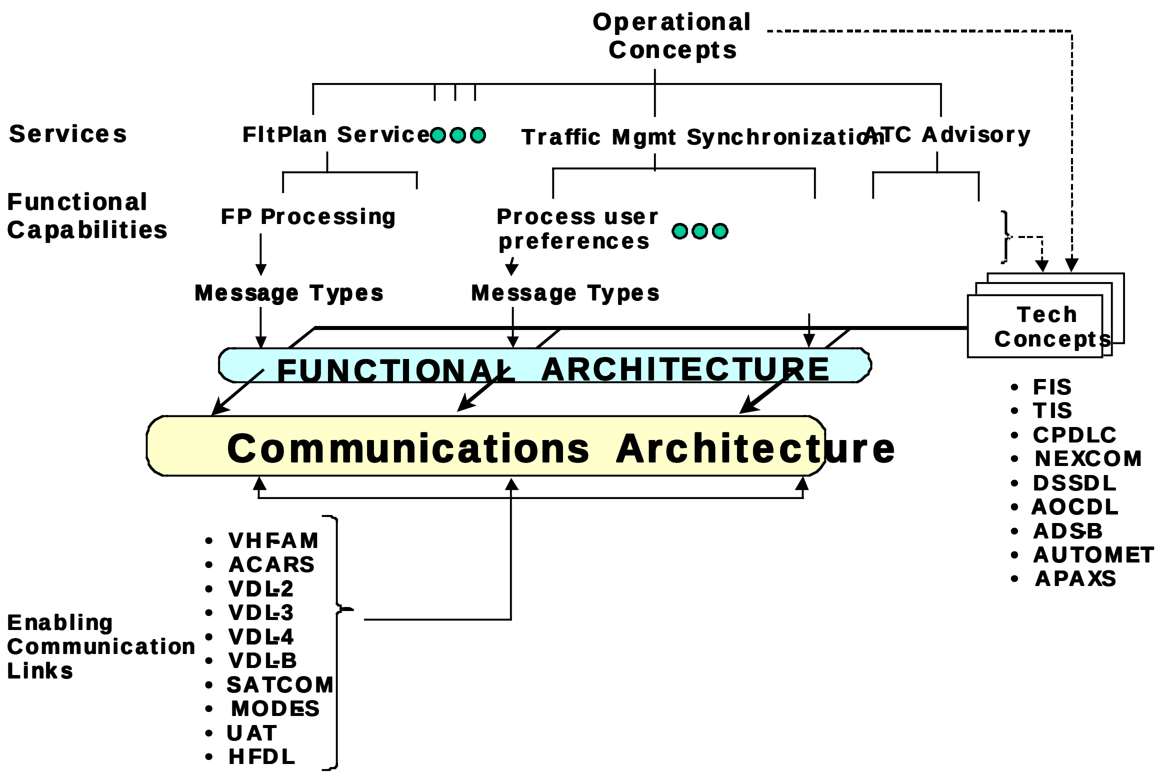

Figure 3.1-2. Operational Concepts to Communications Architecture

At the highest level are the operational concepts that provide the top down vision for what is desired. In the 2015 time frame, the drivers for the operational concepts are born out of the need for increased user flexibility with operating efficiencies and increased levels of capacity and safety to meet the growing demand for air transportation. These concepts are characterized by: (1) removal of constraints and restrictions to flight operations, (2) better exchange of information and collaborative decision making among users and service providers, (3) more efficient management of airspace and airport resources, and (4) tools and models to aid air traffic service providers.

The operational concepts provide a context for measuring progress and for assessing whether or not the infrastructure is being provided to support the vision. The vision provided by the operational concepts draws upon the results of efforts such as the ATS Concept of Operations for the National Airspace System in 2005, the Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM), and current and emerging industry trends. It provides context for the 2007 AWIN Architecture from two perspectives. The first perspective provides a view of the desired 2015 architecture necessary to assess whether or not the 2007 architecture is correctly positioned on the path to 2015. The second perspective provides the broader vision necessary to integrate the 2007 architecture into the overall NAS.

From a communication architecture perspective, it is important to understand the services that will enable the operational concepts along with their supporting functions and the various message types that are the products of those functions. The services identified for this task and their related functional capabilities were identified in Tasks 1, 2, and 3 and are summarized in Table 3.1-1, which also includes the Message Type Identifiers for the information exchange to support these functional capabilities.

Table 3.1-1. Services and Associated Functional Capabilities

Service	Function Name (Functional Capability)	Msg ID (M#)
Aeronautical Operational Control (AOC)	Collaborate with ATM on NAS Projections and User Preferences	M25
	Monitor Flight Progress - AOC	M23
		M33
		M6
	Airline Maintenance and Support	M8-M12
	Schedule; Dispatch; and Manage Aircraft Flights	M30
ATC Advisory Service	Provide In-flight NAS Status Advisories	M17
	Provide In-flight or Pre-flight Traffic Advisories	M32
	Provide In-flight or Pre-flight Weather Advisories	M13
		M14
		M15
		M18
		M20
		M21
		M22
		M26
		M27
		M28
		M29
		M35
		M37
		M39
		M4
		M43
		M44
Flight Plan Services	File Flight Plans and Amendments	M22
		M24
		M32
	Process Flight Plans and Amendments	M16
		M32
		M34
		M40
On-Board Service	Provide Administrative Flight Information	M5
		M7
	Provide Public Communications	M31
Traffic Management Strategic Flow Service	Provide Future NAS Traffic Projections	M38
Traffic Management Synchronization Service	Process User Preferences	M2
	Project Aircraft In-flight Position and Identify Potential Conflicts	M1
		M3
	Provide In-flight Sequencing; Spacing; and Routing Restrictions	M36
	Provide Pre-flight Runway; Taxi Sequence; and Movement Restrictions	M32
		M36

Table 3.1-2 below provides a textual description of the Message Type corresponding to each Message Type Identifier. These messages may be voice, text, or graphical images.

Table 3.1-2. Message Types and Message Type Identifiers

Message Type Identifier	Message Type
M1	ADS
M2	Advanced ATM
M3	Air Traffic Information
M4	Not used – See M43, M44
M5	Airline Business Support: Electronic Database Updating
M6	Airline Business Support: Passenger Profiling
M7	Airline Business Support: Passenger Re-Accommodation
M8	Airline Maintenance Support: Electronic Database Updating
M9	Airline Maintenance Support: In-Flight, Emergency Support
M10	Airline Maintenance Support: Non-Routine Maintenance/ Information Reporting
M11	Airline Maintenance Support: On-Board Trouble Shooting (non-routine)
M12	Airline Maintenance Support: Routing Maintenance/ Information Reporting
M13	Arrival ATIS
M14	Not used – See M43, M44
M15	Convection
M16	Delivery of Route Deviation Warnings
M17	Departure ATIS
M18	Destination Field Conditions
M19	Diagnostic Data
M20	En Route Backup Strategic General Imagery
M21	FIS Planning – ATIS
M22	FIS Planning Services
M23	Flight Data Recorder Downlinks
M24	Flight Plans
M25	Gate Assignment
M26	General Hazard
M27	Icing
M28	Icing/ Flight Conditions
M29	Low Level Wind Shear
M30	Out/ Off/ On/ In
M31	Passenger Services: On Board Phone
M32	Pilot/ Controller Communications
M33	Position Reports
M34	Pre-Departure Clearance
M35	Radar Mosaic
M36	Support Precision Landing
M37	Surface Conditions
M38	TFM Information
M39	Turbulence
M40	Winds/ Temperature
M41	System Management and Control
M42	Miscellaneous Cabin Services

Message Type Identifier	Message Type
M43	Aircraft Originated Ascent Series Meteorological Observations
M44	Aircraft Originated Descent Series Meteorological Observations

Given a definition of the message types that require air-ground communication, the next step was to organize them further in a logical fashion that supports the development of a functional communication architecture. To accomplish this organizational construct, we examined the operational concepts and the service functional capabilities to identify ways to focus the functional architecture. Based on that examination, we defined nine unique technical concepts related to air ground communications that span the functional capabilities and that can be used to drive the definition of the functional architecture. These technical concepts are defined in Table 3.1-3 below:

Table 3.1-3. Air-Ground Communications Technical Concepts

Technical Concept Definition	Technical Concept Name
Aircraft continually receive Flight Information to enable common situational awareness of weather and NAS status	Flight Information Services (FIS)
Aircraft continually receive Traffic Information to enable common situational awareness of the traffic in the area	Traffic Information Services (TIS)
Controller-Pilot data messaging supports efficient Clearances, Flight Plan Modifications, and Advisories	Controller-Pilot Data Link Communications (CPDLC)
Controller-Pilot voice communication to support ATC operations	Controller-Pilot Communications (CPC)
Aircraft exchange performance / preference data with ATC to optimize decision support	Decision Support System Data Link (DSSDL)
Pilot-AOC data messaging supports efficient air carrier/air transport operations and maintenance	Airline Operational Control Data Link (AOCDL)
Aircraft broadcast data on their position and intent continuously to enable optimum maneuvering	Automated Dependent Surveillance-Broadcast (ADS-B)
Aircraft report airborne weather data to improve weather nowcasting/forecasting	Automated Meteorological Reporting (AUTOMET)
Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service	Aeronautical Passenger Services (APAXS)

Using these technical concepts as drivers, we next defined the functional architecture for air ground communications as shown in Figure 3.1-3

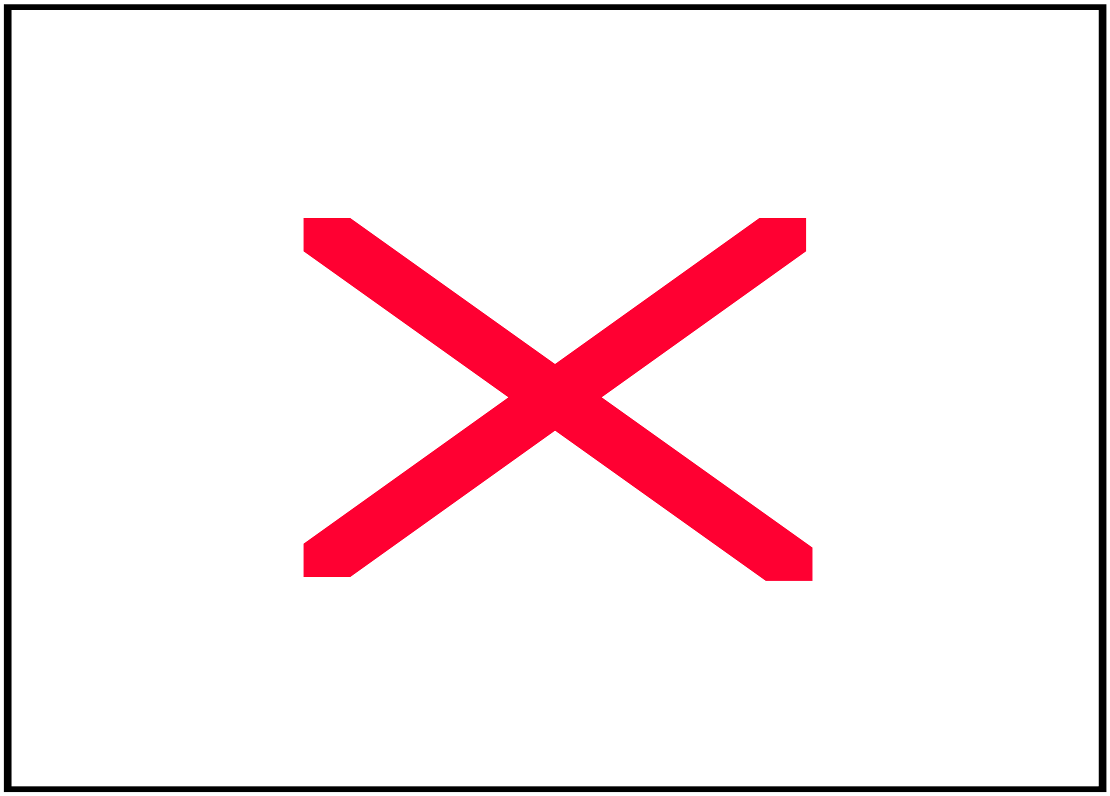

Figure 3.1-3. Functional Architecture for Air-Ground Communications

Our next step was to organize the functional capability message types into categories that are associated with each technical concept. The following table shows the resulting message categories, including message content for each category, mapped to the individual technical concepts listed in Table 3.1-4.

Table 3.1-4. Message Categories Mapped to Technical Concepts

Category.	Technical Concept	Description of Concept
1	Flight Information Services (FIS)	Aircraft continually receive Flight Information to enable common situational awareness
2	Traffic Information Services (TIS)	Aircraft continuously receive Traffic Information to enable common situational awareness
3	Controller-Pilot Data Link Communications (CPDLC)	Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories
4	Controller Pilot Communications (CPC) Voice	Controller - Pilot voice communication
5	Decision Support System Data Link (DSSDL)	Aircraft exchange performance / preference data with ATC to optimize decision support
6	Airline Operational Control Data Link (AOCDL)	Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance
7	Automated Dependent Surveillance (ADS) Reporting	Aircraft continuously transmit data on their position and intent to enable optimum maneuvering
8	Automated Meteorological Reporting (AUTOMET)	Aircraft report airborne weather data to improve weather nowcasting and forecasting
9	Aeronautical Passenger Services (APAXS)	Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service

The organization of message types into the categories listed above is listed in Table 3.1-5 below.

Table 3.1-5. Organization of Message Types into Message Categories

Message Category	Message Category Identifier	Message Type Identifier	Message Type
FIS	1	M13	Arrival ATIS
	1	M15	Convection
	1	M17	Departure ATIS
	1	M18	Destination Field Conditions
	1	M20	En Route Backup Strategic General Imagery
	1	M21	FIS Planning – ATIS
	1	M22	FIS Planning Services
	1	M26	General Hazard
	1	M27	Icing
	1	M28	Icing/ Flight Conditions
	1	M29	Low Level Wind Shear
	1	M35	Radar Mosaic
	1	M37	Surface Conditions
	1	M38	TFM Information
	1	M39	Turbulence
	1	M40	Winds/ Temperature
TIS	2	M3	Air Traffic Information
CPDLC	3	M24	Flight Plans
	3	M29	Low Level Wind Shear
	3	M32	Pilot/ Controller Communications
	3	M33	Position Reports
	3	M34	Pre-Departure Clearance
	3	M41	System Management and Control
DSSDL	5	M2	Advanced ATM
	5	M16	Delivery of Route Deviation Warnings
	5	M24	Flight Plans
AOCDL	6	M9	Airline Maintenance Support: In-Flight Emergency Support
	6	M10	Airline Maintenance Support: Non-Routine Maintenance/ Information Reporting
	6	M11	Airline Maintenance Support: On-Board Trouble Shooting (non-routine)
	6	M12	Airline Maintenance Support: Routing Maintenance/ Information Reporting
AOCDL	6	M19	Diagnostic Data
	6	M23	Flight Data Recorder Downlinks
	6	M25	Gate Assignment
	6	M30	Out/ Off/ On/ In
	6	M8	Airline Maintenance Support: Electronic Database Updating
ADS-B	7	M1	ADS
AUTOMET	8	M43	Aircraft Originated Ascent Series Meteorological Observations
	8	M44	Aircraft Originated Descent Series Meteorological Observations
APAX	9	M5	Airline Business Support: Electronic Database Updating
	9	M6	Airline Business Support: Passenger Profiling
	9	M7	Airline Business Support: Passenger Re-Accommodation
	9	M31	Passenger Services: On Board Phone
	9	M42	Miscellaneous Cabin Services

At this point, having established a functional architecture and a corresponding relationship to the message types, we can combine it with the results of the communication load analysis (section 4.0) and the communication link analysis (Section 5.0) to develop suitable alternative physical communication architectures. This must be performed within the context of the 2015 AATT communications architecture, however, to ensure that the alternatives selected are on a reasonable path to provide a summary of the 2015 AATT architecture (See task 5 for details). The development of alternative architectures for 2007 is the subject of section 3.3.

3.2 2015 AATT Architecture

The 2015 time frame represents the final phases of transition from the era of analog voice communication and islands of diverse information to the new era of digital data exchange through integrated networks using common data. The results of this transition are an integrated collection of systems and procedures that efficiently use the capacity of the NAS while balancing access to all user classes and maintaining the highest levels of safety. As depicted in Figure 3.2-1, efficient collaboration among users is built on a foundation of common data that composes the information base. This data can be logically divided into a static component, representing data that changes infrequently such as maps, charts, etc., and a dynamic component, representing data that changes frequently such as the weather, traffic flow status, and aircraft position. This information base provides common situational awareness to all users who choose to participate. In this time frame, there a variety of users who will choose to participate at various levels of equipage ranging from voice only through multi-mode radios and fully modular avionics. All users are accommodated, however, and will receive benefits commensurate with their levels of equipage.

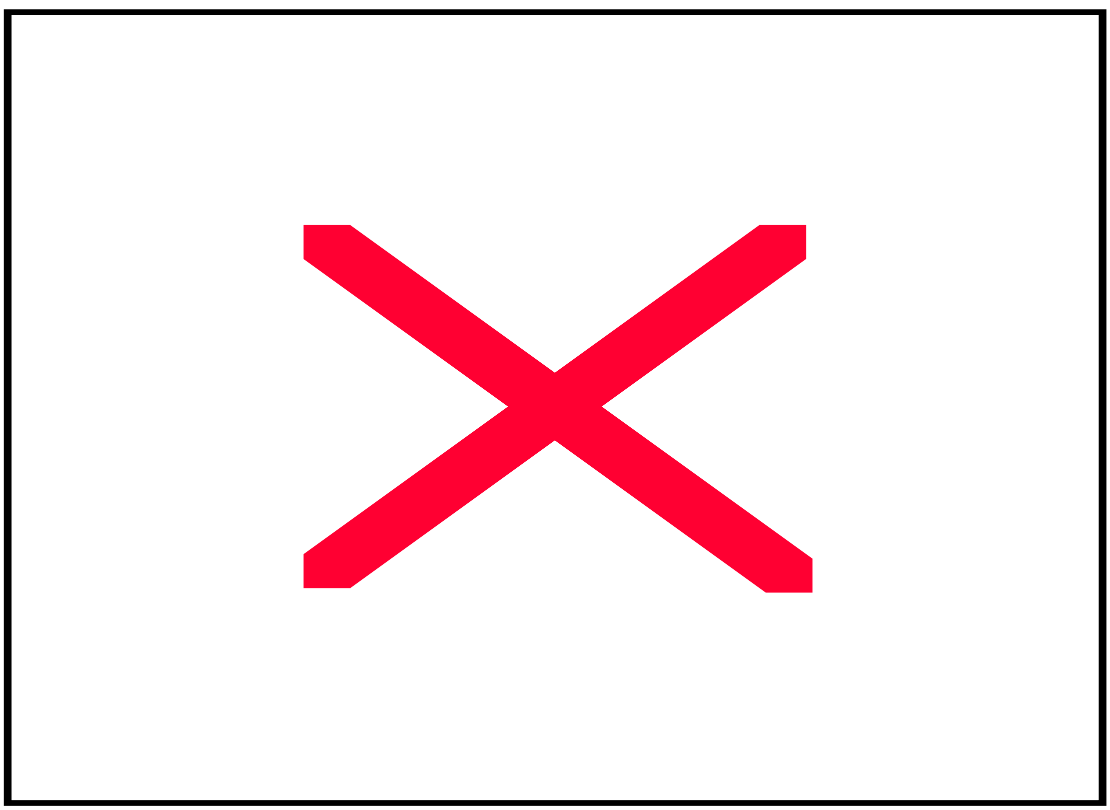

Figure 3.2-1. Air-Ground Communication Levels

The challenge in maintaining the information base is to keep the dynamic data current for all participating users so that optimum decisions can be made. Given a common information base, decision support systems can analyze this data continuously to develop optimum solutions for individual aircraft trajectories as well as trajectories for groups of aircraft. This negotiation takes place between aircraft Decision Support System (DSS) tools and between aircraft and ATC DSS tools. When optimum solutions (or inability to find a solution) are determined, pilots and controllers are notified for confirmation (or other appropriate action). This action takes the form of strategic collaborative decision making or tactical control. In either event, data exchange continues using specified data link messages with voice communication used when it is the only practical means.

For 2015, two alternative architectures are recommended for further study. These alternatives are focused on the selection of a terrestrial or space-based broadband data exchange link (UAT or SATCOM). The 2015 AATT Architecture alternatives are shown in Figure 3.2-2 and Figure 3.2-2.

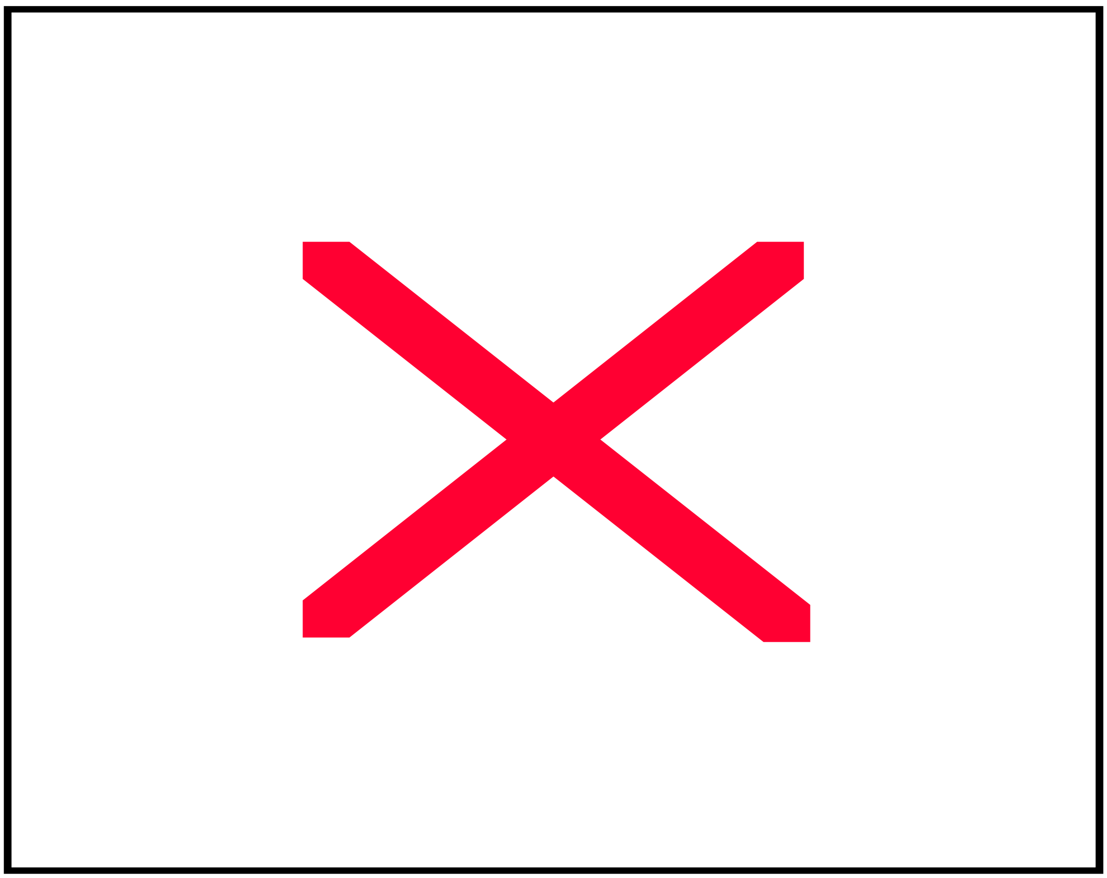

Figure 3.2-2.   2015 AATT Architecture-Terrestrial Based

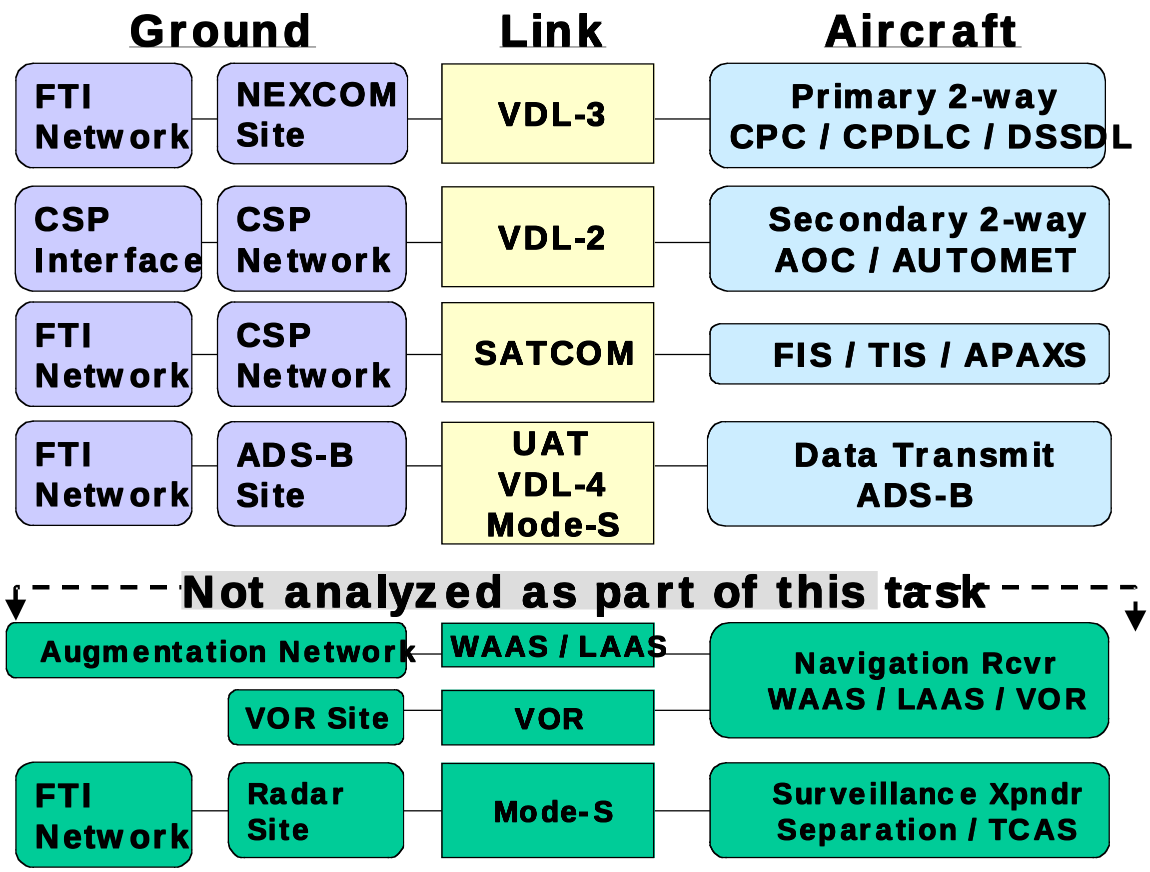

Figure 3.2-3. 2015 AATT Architecture- Space Based

3.3 2007 AWIN Architecture

This section focuses on the definition and development of the weather-related portion of the AATT architecture in the 2007 time frame. Section 3.3.1 describes the operational concept. Section 3.3.2 describes the AWIN-related technical concepts. Section 3.3.3 describes the architecture alternatives developed to satisfy the technical concepts. Finally, Section 3.3.4 identifies the technology gaps that require further research.

3.3.1 AWIN Related Operational Concepts for 2007

The NAS weather architecture was developed to optimize the capability to collect and process weather data, provide current and forecast conditions of hazardous and routine weather, and disseminate that information in text and/or graphical formats to all NAS users and service providers. NAS users include pilots who receive preflight and in-flight weather information, flight planners, air traffic controller specialists, airline and vendor meteorologists, and airline dispatchers.

In 2007, the NAS is in transition toward the establishment of common data sharing among service providers and users that form the basis for collaborative management of the air traffic control system. Concepts such as Free Flight and DAG-TM call for more distributed control of aircraft movement and less dependence on government services. From a communication perspective, these paradigm shifts result in the need for greater communication throughput, as the volumes of data increase.

The NAS infrastructure has evolved to an integrated weather system supported by WARP and ITWS. These systems convert “raw” weather data into meaningful information and act as weather servers for the NAS wide information system. This allows near simultaneous delivery of weather data and products to both users and service providers, resulting in an enhanced common situation awareness.

In addition to supplying weather information to the cockpit, some aircraft operators choose to equip their aircraft with weather sensors that can report data to the ground, including temperature, winds aloft, humidity, and turbulence. This data is used by the NWS to supplement forecast models, resulting in more accurate forecast data for use by ATC decision support systems.

In addition to data linked ATIS, clearance delivery, and taxi instructions, basic meteorological information, such as current and forecast weather and pilot reports (PIREPs), is available in the cockpit, as are current weather maps. Additionally, in this time frame, there is increasingly accurate weather information available to the service provider and user, including hazardous weather alerts for wind shear, microbursts, gust fronts as well as areas of precipitation, icing, and low visibility.

From a pilot’s perspective, this data is provided through commercial flight information service providers. These providers receive weather and NAS status information from the FAA (and other sources) and provide it (using FAA and Commercial spectrum) to pilots for a subscription fee. As part of the FAA’s flight information services policy, the FAA will approve the basic weather data that a commercial service provider will provide to the cockpit. This has the greatest impact on the Class 1 users, since this information is already available to Class 2 and 3 users through their AOCs.

An increase in collaboration among users and service providers for both planning and strategic problem resolution emerges as a result of increased information exchange. Databases and decision support systems that use these databases enable a shared view of traffic and weather among all parties so that proposed strategies can be evaluated. For example, in a severe weather situation, increased collaboration among users and service providers enables shared decisions on how to avoid the severe weather and deal with the resultant short-term capacity shortage.

The weather related portions of the technical concepts identified in Section 3.1 are as follows:

Technical Concept Definition	Technical Concept Name
Aircraft continuously receive Flight Information to enable common situational awareness	Flight Information Services (FIS)
Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	Controller-Pilot Data Link Communications (CPDLC)
Controller - Pilot voice communication	Next Generation Communications (NEXCOM)
Aircraft report airborne weather data to improve weather nowcasting/forecasting	Automated Meteorological Reporting (AUTOMET)

Accordingly, the functional architecture for AWIN is a shown in Figure 3.3-1.

Category	Technical Concept	VDL-B	VDL-2/ATN	VHF-AM	UAT	SATCOM-2 way
1	FIS	■ ◇			◇	◇
4	CPC (voice)			■ ◇		
8	AUTOMET		■ ◇		◇	◇

◇ Technically Feasible
■ NAS Architecture

Figure 3.3-1. AWIN Functional Architecture

Each technical concept associated with the AWIN architecture is described in Section 3.3.2. Figures showing the end-to-end systems and communication links for the technical concepts are provided as part of the description. The figures identify the significant ground systems, air-ground communication links, and aircraft systems.

3.3.2 Technical Concepts

3.3.2.1 Flight Information Services (FIS)

The FIS technical concept does not change from that projected for 2015. FIS provides one of the foundation functions for maintaining the static and dynamic data requirements for the information base of the NAS. In this concept, aircraft receive flight information continuously in order to enable common situational awareness for pilots that support their ability to operate safely and efficiently within the NAS. Flight information consists of NAS weather information, NAS status information and NAS traffic flow information. Flight information is considered advisory and for the purposes of air-ground communications is classified as routine (see section 4.2 for further details). FIS information is intended for transmission to all classes of users. Thus, any selected link alternative must be capable of installation and use in most any aircraft regardless of class. The single line diagram for FIS is shown in Figure 3.3-2.

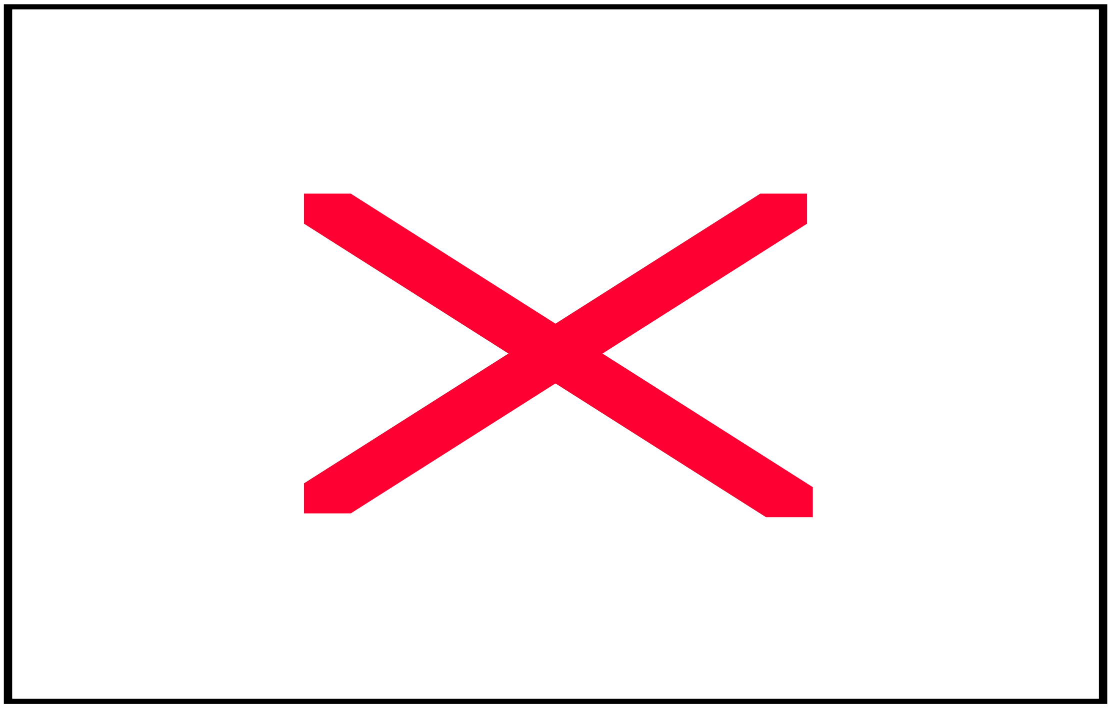

Figure 3.3-2. Flight Information Service in 2007

The Weather products transmitted via FIS may include observations and forecasts, weather radar data, winds and temperature aloft, and gridded forecast data. The NAS status information may include NOTAMs, airport conditions and configurations, and active/inactive status of special use airspace. NAS traffic flow information may include active and pending restriction data, and other traffic flow initiative information.

During the requirements analysis conducted in Tasks 1 through 3, it was thought that some types of FIS products might be tailored for a specific flight and delivered only to an aircraft that requested it, while other FIS products were not flight specific and would be suitable for broadcasts. In this form the messages require conversion from 2-way to broadcast or vice versa for our analysis. These message types are shown in Table 4.3-3 and Table 4.3-4 respectively.

For FIS, the NAS Architecture plans to rely on two commercial service providers to supply products regionally to the aircraft, via two allocated 25kHz VHF frequencies each, using VDL-B.

Our communication load estimate for broadcast FIS is the same for 2007 as for 2015 as we were unable to identify any additional products that could be added after 2007. The FIS load data is derived from Table 4.5-6 and Table 4.5-7.

For the initial analysis, the architecture was evaluated with FIS data transmitted to the aircraft using a two-way (request/reply) data link or a transmit-only broadcast data link, depending on the message type. This was based on the requirements identified in Tasks 2 and 3.

In order to get a domain broadcast estimate we combine the FIS flight specific and non-flight specific data (Table 4.3-3, Table 4.3-4) and make the appropriate unit conversions to produce Table 3.3-1. For purposes of estimation, if we assume a region consisting of one en route center, a consolidated terminal area and four airports, then the total communication requirement for the region would be 7.2 kbps on the broadcast link and 66 kbps on the two-way link. This greatly exceeds the capacity of a VDL channel, precluding use of this approach on the channels currently allocated for FIS. In addition, this approach would require the use of separate radios for broadcast and two-way FIS and complicated avionics to combine the results on a display.

Table 3.3-1. FIS 2-Way + Broadcast Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
FIS – Domain	9.9	9.4	17.2	
Region (x) [1]	39.6 (4)	9.4 (1)	17.2 (1)	66
FIS - Regional Broadcast		0.6	66	7.2

Note: (x) is domain multiplier

Even for information of a general nature, it could be delivered to every flight over two-way links. Given the dynamic nature of FIS data, however, a two-way data link would require a constant request/reply method that is inefficient in terms of channel overhead and suffers in performance directly proportional to the number of aircraft (see Section 4.3.2). Our estimate of the two-way communication loading for FIS (if all messages were two-way) identifies the need for uplinks ranging up to 1265 kbps in 2007 for a geographic area covering the airspace of; four airports, a consolidated TRACON, and encompassing en route airspace. This far exceeds any VDL link capacities and would require a move to broadband links. Detailed analysis included applying overhead factors for two-way communications to all non-flight specific messages; since this is not considered a viable solution, the details analysis is not included here.

From a communication standpoint, broadcast communication is considered desirable for FIS because it is the most efficient in terms of overhead and component design. This is the method currently being employed by the FIS service providers in selected areas.

If the messages identified in Table 4.3-3 as two-way messages for FIS were instead broadcast, at the same frequencies as shown in the table, the total communication load would be reduced to the loads shown in Table 3.3-2. Note that the communication load is reduced not only because products are transmitted only once for all aircraft to receive, but also because the protocol overhead for broadcast is less than the overhead for two-way communication.

Table 3.3-2. FIS Communication Load Requirements (kilobits per second) to Broadcast all FIS Message Types

	Airport	Terminal	En Route	Total
FIS - Domain	0.2	0.9	6.9	
FIS - Region	1.0 (5)	4.5 (5)	6.9 (1)	12.4
FIS - National				248 (20)

Note: (x) is domain multiplier

Using the same example of a region (en route airspace including five airports and their related terminals) the total load requirement is 12.4 kbps. This is within the capacity of a VDL-B channel. One disadvantage of regional coverage is that the pilot can only receive FIS data for the region that they are flying in. In some situations, this can limit the pilot's ability to perform strategic planning.

Aggregation of this data to a national level can conservatively be estimated by multiplying the regional estimate by 20 (the number of CONUS centers). This yields a national broadcast load of 248 kbps. This would exceed the capacity of any VDL link but could be supported by the broadband UAT or SATCOM links.

Table 3.3-3. FIS Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft continuously receive Flight Information to enable common situational awareness	FIS					✓		✓	✓	
✓ Acceptable Alternative		▭ NAS Architecture	◯ AATT CSA Recommendation							

3.3.2.2 Controller-Pilot Communications (CPC)

Voice communication is the foundation of air traffic control. Thus, even as we move toward a higher utilization of data exchange for routine communications, it is critical to maintain a high quality, robust voice communication service. Voice communications remain unchanged from the pilots and controllers perspective in 2007. From a technical perspective, the implementation of digital technology radios (that continue to operate in the DSB-AM mode) provide higher reliability, ease of maintenance, and are the first step toward implementation of VDL-3. The concept for CPC is shown in Figure 3.3-3.

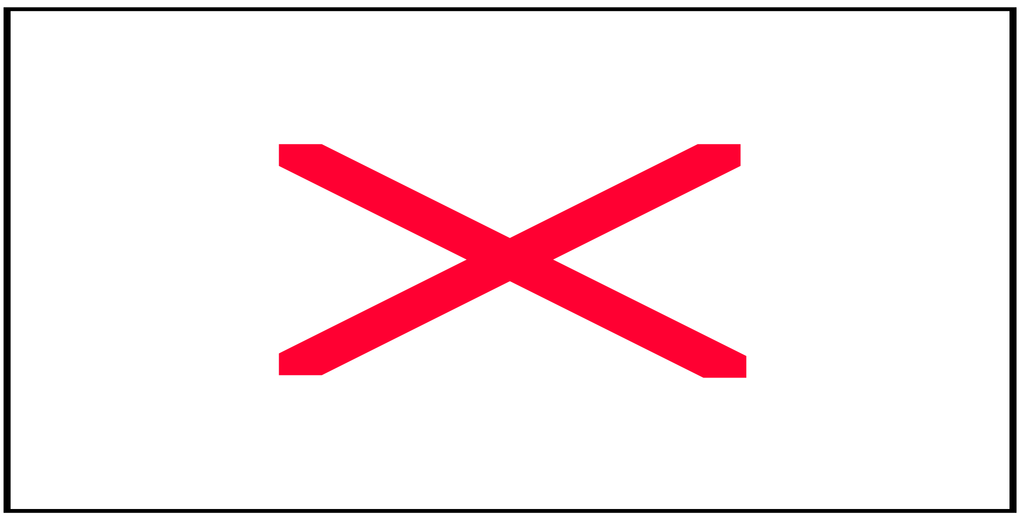

Figure 3.3-3. CPC Air/Ground Voice Communication in 2007

The CPC communication links are shown in Table 3.3-5. The NAS Architecture plans to transition controller pilot voice communication to an FAA supported VDL-3 network in the 2010-2015 time frame. Our VDL-3 link analysis indicates that a single VDL-3 sub-channel supports 4.8 kbps. Our communication load analysis indicates that a single VDL-3 sub-channel is sufficient to support controller pilot communication under worst case loading conditions. We therefor recommend that the AATT CSA maintain the NAS Architecture recommendation.

Table 3.3-4. CPC Load Analysis Results

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	2.6	1.2	1.0	1.0	3.0	0.8
2	0.8	0.4	0.8	0.8	0.4	0.2
3	1.0	0.4	0.8	0.8	0.5	0.2
Total	6.3		5.3		5.2	
Voice Channels Required (P=0.2)	9		8		8	

The CPC communication links are shown in Table 3.3-5. The NAS Architecture plans to transition controller pilot voice communication to an FAA supported VDL-3 network in the 2010-2015 time frame.

Table 3.3-5. CPC Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Controller - Pilot voice communication	CPC	✓								

✓ Acceptable Alternative | NAS Architecture | AATT CSA Recommendation

3.3.2.3 Automated Meteorological Transmission (AUTOMET)

The definition of AUTOMET is currently under the auspices of RTCA Special Committee 195 which has developed Minimum Interoperability Standard (MIS) for Automated Meteorological Transmission of wind, temperature, water vapor and turbulence (RTCA DO-252). Conceptually, aircraft participating in the AUTOMET service must be able to respond to AUTOMET commands issued by a ground-based command and control system. Downlink message parameters (e.g., frequency, type, etc) are changed by uplink commands from the ground-based systems and are triggered by various conditions (agreed to in advance by the aircraft operator, commercial service provider, and AUTOMET product user). Goals of the AUTOMET system are: 1) Increase the amount of usable weather data that is provided to the weather user community; 2) Increase the resolution of reports, forecast products and hazardous weather warnings to make providers of weather information more operationally efficient; 3) Increase the knowledge of the state of the atmosphere and decrease controller workload by automatically transmitting hazardous weather conditions to the ground and other aircraft to improve the ATC system. The AUTOMET single line drawing is shown in Figure 3.3-4.

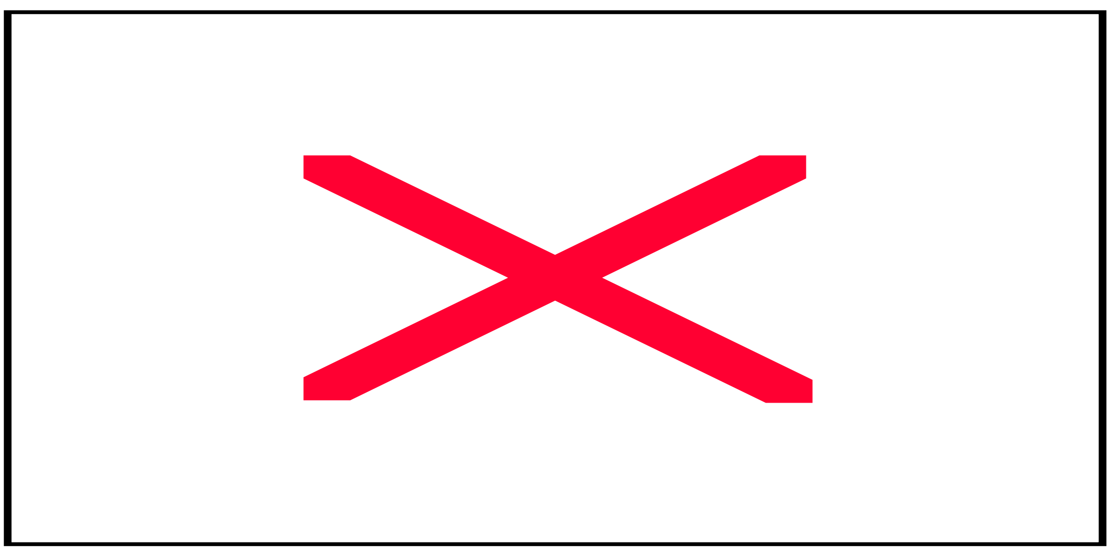

Figure 3.3-4. Automated Meteorological Transmission (AUTOMET) in 2007

In our AUTOMET concept aircraft collect wind, temperature, humidity, and turbulence information in flight and automatically relay the information to a commercial service provider. The service provider collects (and for some users reformats) the information and then forwards it to the AUTOMET product users. Functionally, there are a number of users of "AUTOMET" data today, albeit under different names. Some examples are:

Name	User
MDCARS, E-MDCRS	NOAA, NWS
ACARS	NOAA, FSL AOC
EPIREPS	NASA

For our analysis, these are treated as functional equivalents under the name AUTOMET. The NWS uses AUTOMET information and weather data from other sources to generate gridded weather forecasts. The improved forecasts are distributed to airlines and the FAA to assist in planning flight operations. The gridded weather data, based on AUTOMET data, is also provided to WARP, for use by FAA meteorologists and by several ATC decision support system tools to improve their predictive performance.

Our communication loading analysis for AUTOMET is shown in Table 3.3-6 for each domain. For AUTOMET we assume that no data will be transmitted in the airport domain since there are other sensors that provide that data and it is poor use of a communication channel to have many aircraft transmitting the same data. The worst case load for AUTOMET should occur in a high-density terminal domain within a high-density en route domain. Thus, we use our worst case terminal and en route aircraft forecast to develop the communication load estimate.

AUTOMET equivalent data is transmitted today over the ACARS network. We believe that this data transmission will migrate to the VDL-2 network by 2007. Given that the effective data rate of a single VDL-2 channel is 19.2 kbps, there is sufficient capacity on the VDL-2 network to support AUTOMET. The UAT or SATCOM links could also support AUTOMET, but we believe that this would be unlikely to occur given current plans. A summary of the viable communication links for AUTOMET is shown in Figure 3.3-7

Table 3.3-6. AUTOMET Communication Load Requirements (kilobits per second)

	Airport	Terminal	En Route	Total
AUTOMET	N/A	1.2	1.7	
Worst Case	N/A	1.2 (1)	1.7 (1)	2.9

Note: (x) is domain multiplier

Table 3.3-7. AUTOMET Communication Links

Operational Concept	Technical Concept	VHF-AM	VDL-2/ ATN	VDL-3/ ATN	VDL-4/ ATN	VDL-B	Mode-S	UAT	SATCOM-Broadcast	SATCOM-2way
Aircraft report airborne weather to improve weather nowcasting/forecasting	AUTOMET		✓					✓		✓
✓ Acceptable Alternative		NAS Architecture		AATT CSA Recommendation						

3.3.3 2007 AWIN Architecture Alternatives

The applicable communication links described in the previous section can be summarized in the following table:

Category	Technical Concept	VDL-2/ ATN	VDL-B	VHF-AM	UAT	SATCOM
1	FIS		✽		✽	✽
4	CPC			✽		
8	AUTOMET	✽			✽	✽

In theory, any combination of links that address all technical concept areas will form a valid communication architecture. Our approach to creating architecture alternatives was to begin with the NAS Architecture and then consider terrestrial and space-based alternatives.

3.3.3.1 Architecture Alternative 1 - NAS Architecture

The NAS Architecture is the aviation community's comprehensive, 15-year (strategic) plan to modernize the NAS. The objective of NAS modernization is to add new capabilities to improve efficiency, safety and security while sustaining existing services. The NAS Architecture is unique in that it combines the technical aspects of a traditional architecture with their related programmatic aspects (i.e. cost and schedule). It is this combination of programmatic and technical aspects, in the context of the NAS as a whole, that results in a baseline consistent with FAA priorities and schedules.

The communication portion of the NAS Architecture for 2007 was selected as AWIN Architecture Alternative 1 because it reflects the current thinking, priorities, and funding by the FAA and aviation community. This NAS communication architecture baseline has allocated funding consistent with the planning, acquisitions, and implementation of communication and weather systems. The other AWIN architecture alternatives will use this alternative as their reference for comparison.

The NAS Architecture recognizes that weather conditions interfere with flight operations and are a significant contributor to aviation accidents. Therefore the NAS Architecture baseline provides for improved ways to collect, process, transmit, and display weather information to users and service providers during flight planning and while in-flight. The key to reducing weather -related accidents is to improve pilot decision-making through increased exchange of timely weather information.

The NAS weather architecture for 2007 will evolve from today's stand-alone systems to one where weather systems are integrated into a weather server concept (wherein common weather information is available to all authorized participants) to enhance safety and efficiency by promoting common situational awareness. The NAS weather architecture attempts to optimize the capability to collect and process weather data, provide current and forecast conditions of hazardous and routine weather, and disseminate information in text and or graphical formats. NAS users include pilots who receive preflight and in-flight weather information, flight planners, airline and vendor meteorologists, and airline dispatchers. Service providers include ATC personnel, traffic management specialists, and flight service specialists.

The NAS weather systems are briefly described to provide the context to understand the air-ground and ground-ground communications necessary to support AWIN. The NAS weather systems are categorized into 1) weather sensor and/or data sources and 2) processing and display systems. Improved weather sensors and data sources include the Next Generation Weather Radar (NEXRAD), Terminal Doppler Weather Radar (TDWR), and ground and aircraft-based sensors. NEXRAD processing and dissemination capabilities will be improved to provide higher resolution weather information such as wind speed and direction for precipitation, convective activities, tornadoes, hail, and turbulence. TDWR provides alerts of hazardous weather conditions in the terminal area and advanced notice of changing wind conditions to permit timely change of active runways. Other sensors will be upgraded or replaced to take advantage of evolving sensor technology. Aircraft functioning as sensors for weather data will become a key element in improving the accuracy of weather forecasts and will support validation of new weather algorithms. The airborne sensors will collect real-time information such as winds aloft, temperature, and humidity for downlink to ground facilities for distribution.

The key processing and display systems for 2007 are the deployment of the Integrated Terminal Weather System (ITWS) and the Weather and Radar Processor (WARP). These systems act as weather servers that convert multiple sources of weather data into meaningful information. ITWS acquires, processes, and disseminates weather products to other systems and users in the terminal domain and WARP in the en route domain. ITWS provides NEXRAD and TDWR data and improved forecasts to the controller’s traffic displays at TRACONs and air traffic control towers (ATCT) and terminal weather information to ARTCCs. At an ARTCC, WARP provides a mosaic of NEXRAD data for controller’s traffic displays and improved weather data to meteorologists and traffic managers. Decision support tools such as conflict probe and traffic management advisor also benefit from improved weather data. The Operational and Supportability Implementation System (OASIS) receives weather information from WARP and provides weather products to the flight service specialists to assist in flight planning. Pilots access weather products at the FSS using OASIS or use Direct User Access Terminals (DUATS) for self-briefing and filing of flight plans.

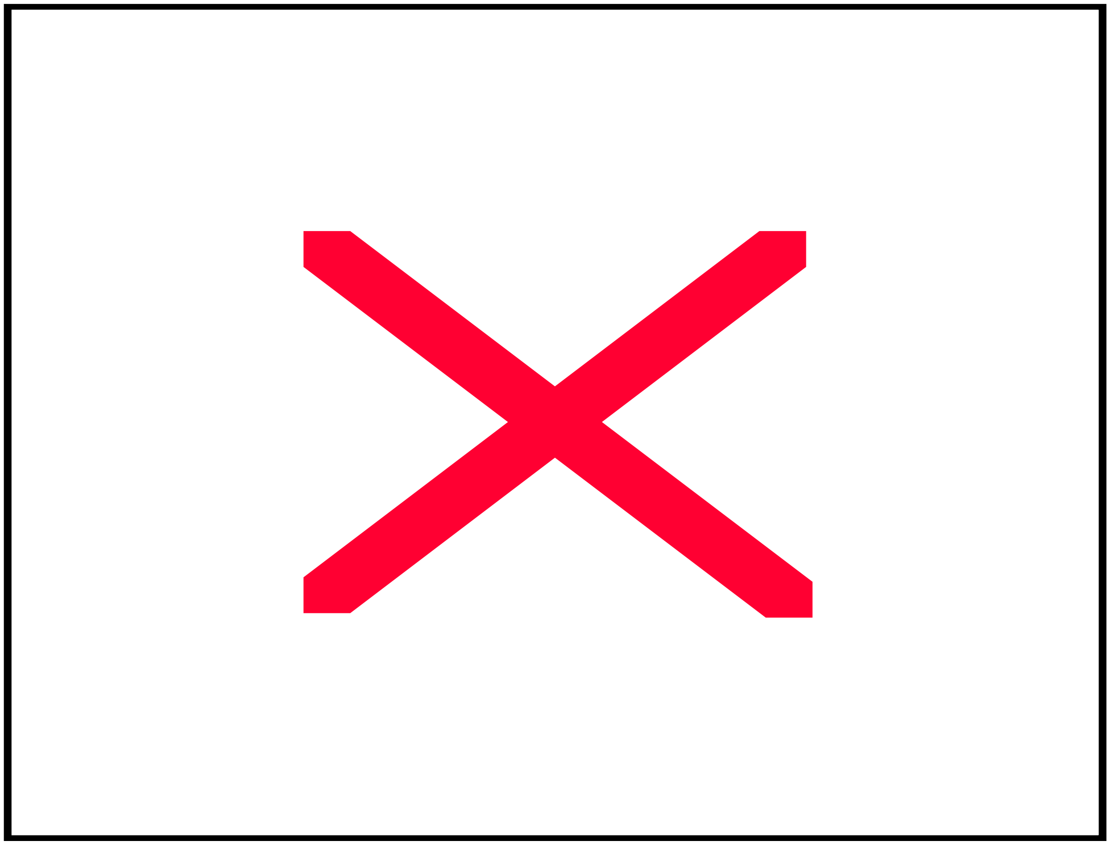

Figure 3.3-5. 2007 AWIN Architecture Alternative 1 - NAS Architecture

A diagram of the 2007 AWIN Air-Ground Communication Architecture consistent with the baseline NAS Architecture is shown in Figure 3.3-5. The current NAS Architecture baseline is terrestrial-based and focused on the use of VHF data links. There are no plans in the current NAS architecture to explore the use of SATCOM for any applications beyond ground-ground communications, oceanic communications, or GPS augmentation. It is assumed that the FAA Telecommunication Infrastructure (FTI) will provide the necessary bandwidth and routing/switching services to support ground-ground communications.

The NAS Architecture baseline for FIS in the 2007 timeframe is to allocate two VHF frequencies to each of two commercial service providers to deliver weather information to the cockpit via VDL-B. Users will need to equip their aircraft with a VHF data radio (likely multi-mode radios) and a color multifunction display to receive and display the information.

Controllers at FSSs, ARTCCs and other ATC facilities will continue to use voice communications to provide weather information to aircraft either directly when requested or via broadcast. Voice communications are also used for pilot reports (PIREPs) of weather conditions. In the 2007 timeframe, NEXCOM digital technology radios will replace many of the existing analog technology radios. In this time frame, however, these radios will emulate the existing DSB-AM modulation. Transition to digital voice will begin in 2010.

Aircraft participating in AUTOMET collect wind, temperature, humidity, and turbulence information in-flight and automatically relay the information to a commercial service provider using VDL Mode 2. The service provider collects and — in some cases — reformats the information and forwards it to the National Weather Service (NWS) and other participating organizations. The NWS uses this AUTOMET information and weather data from other sources to generate nowcast/forecast products. The improved forecasts are distributed to airlines and the FAA to assist in planning flight operations. The gridded weather data based on AUTOMET data is also provided to the WARP weather network for use by FAA meteorologists and ATC decision support system tools.

A summary of the 2007 AWIN architecture alternative contained in the baseline NAS Architecture is provided in Table 3.3-8 below.

Table 3.3-8. AWIN Architecture Alternative 1 - NAS Architecture Summary

Technical Concept	2007 NAS Weather Architecture
Flight Information Service (FIS)	• Regional weather products delivered by commercial service provider using VDL broadcast • Controllers or flight service specialist continue to provide weather services using existing VHF analog voice communications
Controller-Pilot Communications (CPC)	• Weather advisories, PIREPs and other information still passed between aircraft users and ground ATC by voice communications • NEXCOM digital technology radios replace existing VHF analog technology radios (emulate DSB-AM Modulation)
Automated Meteorological Transmission (AUTOMET)	• Participating aircraft collect in-flight meteorological data and automatically transmit data to commercial service provider using VDL Mode 2 • Service provider forwards–and in some cases, reformats– weather information to participating organizations

3.3.3.2 Architecture Alternative 2 - Terrestrial-Based Architecture

A diagram of the 2007 AWIN Alternative 2 Architecture shown in Figure 3.3-6. The major change from Alternative 1 is the addition of a broadband UAT link to support FIS.

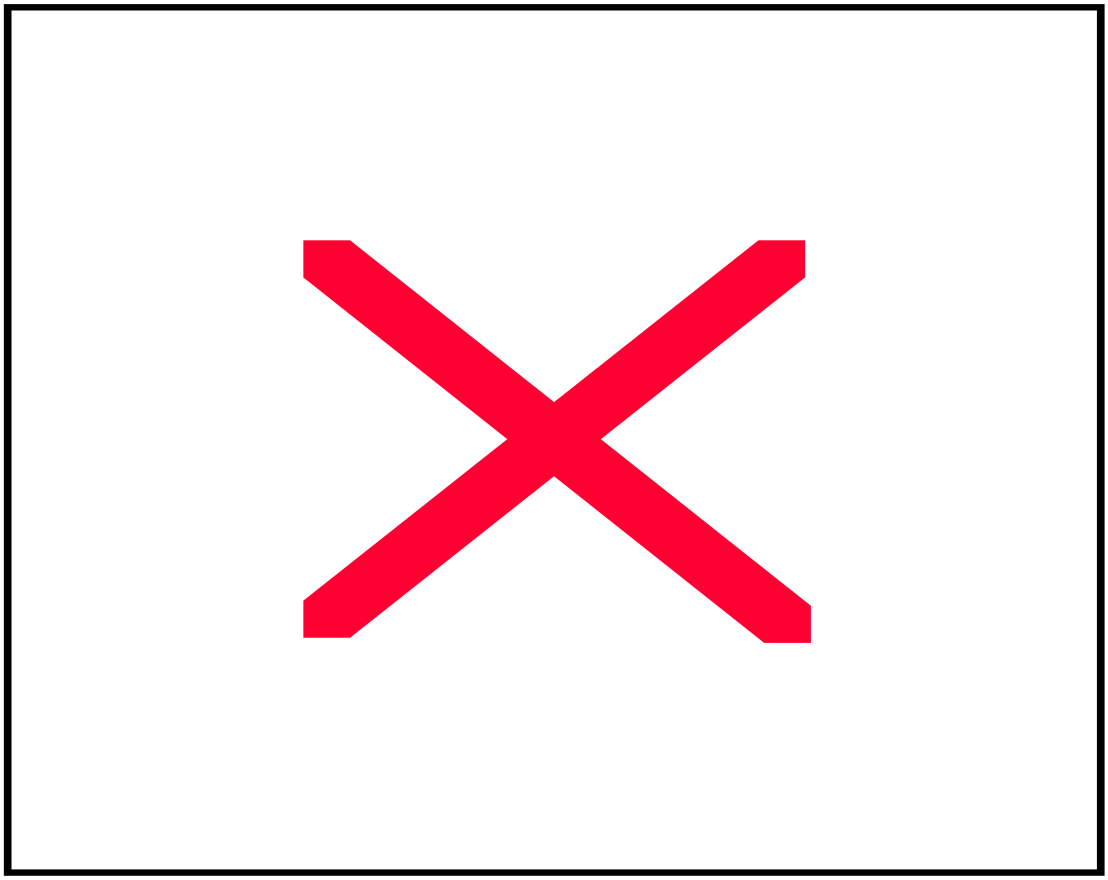

Figure 3.3-6. 2007 AWIN Architecture Alternative 2 - Terrestrial-Based Architecture

The implementation of UAT in a terrestrial network that provides CONUS coverage would most likely result from the selection of UAT as the communication link for ADS-B. The FAA and EUROCONTROL are expected to make an ADS-B link decision in 2001. If UAT is selected the FAA would begin deployment of UAT in “local pockets” beginning in the 2004/2005 time frame, with National deployment complete in the 2010-2012 time frame. It is assumed that these UAT sites will be established with broadband connectivity to the FTI network either directly or via a commercial service provider —and that dedicated frequencies will be allocated for FIS. These FIS frequencies (and potentially the operation of the communication sites) may be allocated to commercial service providers with similar provisions as the current FIS policy. A terrestrial broadband UAT network provides the capacity to transmit regional and national FIS data. This extends the situational awareness of the pilot and supports strategic flight planning in the cockpit. The UAT link is currently being tested as part of the Safe Flight 21 program in Alaska and the Ohio River Valley.

The comparison of AWIN Architecture Alternative 2 to the baseline NAS Architecture for 2007 is summarized in Table 3.3-5 below.

Table 3.3-9. 2007 AWIN Architecture Alternative 2 Comparison to NAS Architecture

Technical Concept	SATCOM Broadcast Architecture Differences
Flight Information Service (FIS)	• National FIS data set broadcast using non addressed UAT communications to properly equipped aircraft • Commercial service providers continue to make weather products available to users using VDL broadcast during transition to UAT
Controller-Pilot Communications (CPC)	• Same as baseline 2007 NAS Architecture alternative described in Section 3.3.1.
Automated Meteorological Transmission (AUTOMET)	• Same as baseline 2007 NAS Architecture alternative described in Section 3.3.1.

3.3.3.3 Architecture Alternative 3 - Space-Based SATCOM

A diagram of the 2007 AWIN Alternative 3 Architecture is shown in Figure 3.3-7. This alternative is identical to Architecture Alternative 2 with the exception that FIS data is provided via SATCOM.

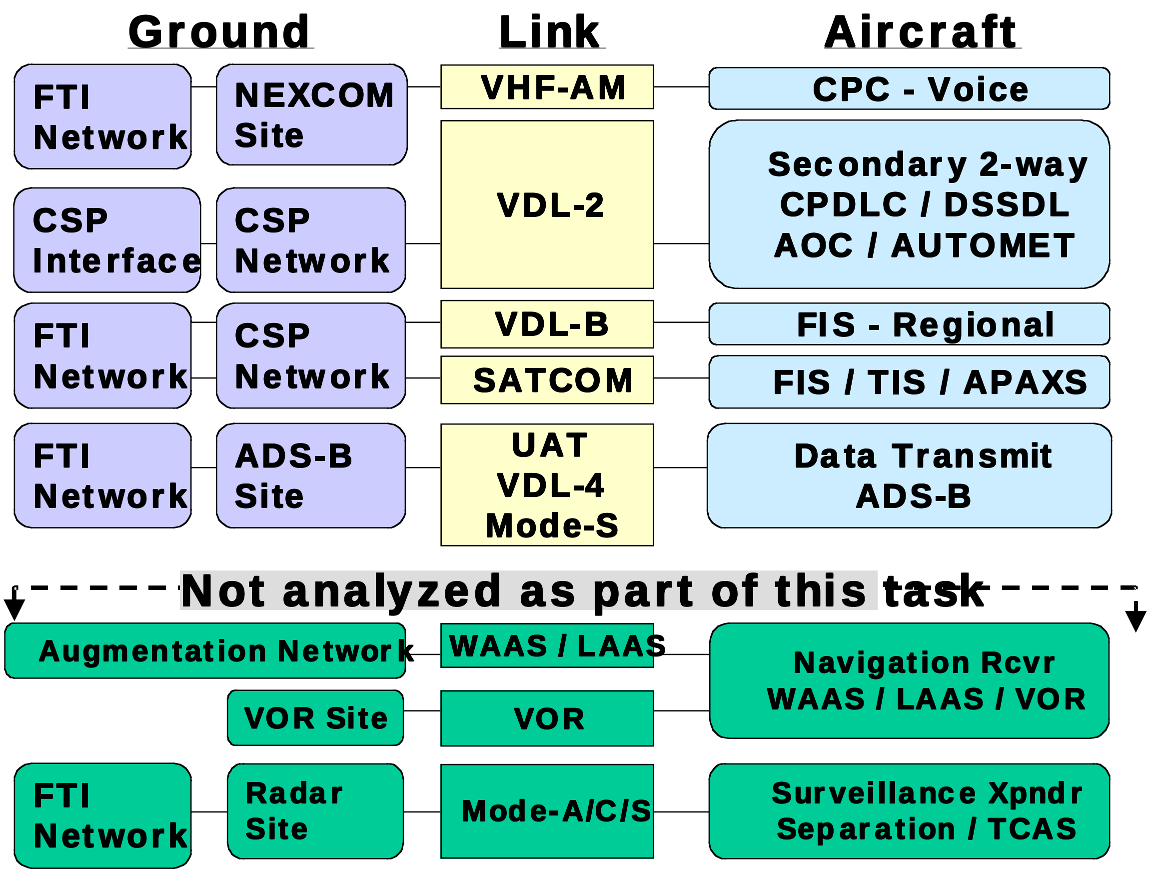

Figure 3.3-7. 2007 AWIN Architecture Alternative 3 - SATCOM Two-way

This AWIN architecture alternative implements a two-way satellite request/reply architecture to disseminate routine and flight specific weather data as part of the FIS concept. The volume of weather data today and its inevitable increase in the future along with the desire to include multi-regional or national data does not lend itself to distribution via VDL. Furthermore, the emergence of satellite technology – with data transmission rates hundreds of times that of VDL and broader coverage – in the near term offers the promise of a full collection of weather products available to the pilot throughout the flight. If UAT is not chosen for ADS-B there will be n motivation for the FAA to establish a terrestrial broadband air-ground network. Absent a terrestrial network, SATCOM is the only viable method for providing CONUS-wide broadband data. We believe that broadband satellite technology satisfies the requirements, and could be demonstrated by 2004. Further, we believe that commercial demand for broadband aeromobile services will be the primary driver for SATCOM implementation.

The comparison of AWIN Architecture Alternative 3 to the baseline NAS Architecture for 2007 is summarized in Table 3.3-10 below.

Table 3.3-10. 2007 AWIN Architecture Alternative 3 Comparison to NAS Architecture

Technical Concept	SATCOM Two-way Architecture Differences
Flight Information Service (FIS)	• FIS data set sent to properly equipped aircraft using two-way satellite communications • Commercial service providers continue to make weather products available to users using VDL broadcast during transition to SATCOM
Controller-Pilot Communications (CPC)	• Same as baseline 2007 NAS Architecture alternative described in Section 3.3.1.
Automated Meteorological Transmission (AUTOMET)	• Same as baseline 2007 NAS Architecture alternative described in Section 3.3.1.

3.3.4 Technology Gaps

To determine if technology gaps existed in any of our architecture alternatives we created “single line” drawings for each of the technology concepts. The purpose of the single line drawing is to highlight the end-to-end connectivity required at the concept level to be able to execute the technical concept. This provides a structure that allows us to determine technical as well as concept gaps.

For gap consideration, the technologies must have the potential to be implemented by 2007. Furthermore, activities to close the gap must be demonstrable no later than 2004. To determine if a gap exists we used the following criteria:

- Invention required - no technology exists
- Experimentation required - no demonstrated application exists
- Focused research required - no aviation-related integration exists
- Standards development required – no International aeronautical standards exist
- Certification and engineering required - no certified systems exist

Each single line drawing contains all of the communication links that were identified in any of the architecture alternatives so that any gap associated with a particular technical concept can be seen. The following paragraphs address the technology gaps identified for each technical concept.

3.3.4.1 Flight Information Services

Flight information services is the most significant technology concept for AWIN. As discussed in the previous architecture alternatives section, the NAS Architecture relies on a commercial service provider(s) to disseminate weather products via VDL-B. Our analysis of future FIS data exchange requirements in section 4 indicates that the imagery and weather data requirements will exceed the capabilities of a VDL-B link as described in section 4.3. To remain a viable alternative, higher data compression schemes for VDL-B must be researched as a means to keep up with expanding data demands.

Use of satellite communication links requires the demonstration of aeronautical mobile technologies for antenna, receivers, link algorithms, protocols, and standards. A major technology focus for broadband communications services is the need to provide more bandwidth (i.e., a focus on Ka-band). Given the migration to these frequencies, the need exists for higher efficiency transmitters (both space and terrestrial), more adaptive bandwidth versus power efficient modulation, forward error correction coding (including turbo codes and bit/modulation symbol interleaving), and much expanded use of the variable bit rate formats of dynamic multiplexing techniques such as asynchronous transfer mode (ATM) based technologies. Antennas and receivers must be adapted for the aviation market (size, weight, cost) and must overcome the problems of rain attenuation for broadcast FIS over satellite.

In addition to the communication gaps identified for FIS, there are ground and aircraft gaps that must also be addressed, these are; common data standards, NWIS security and routing protocols for delivery of FIS data, and data display standards for the cockpit.

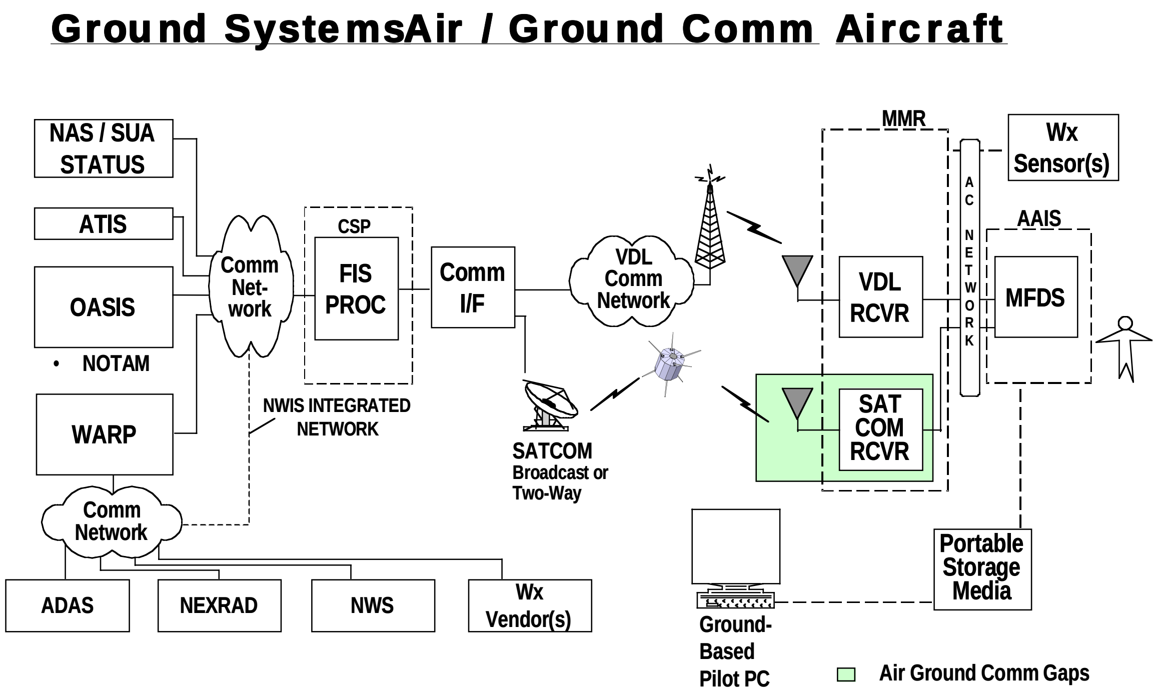

Figure 3.3-8. Flight Information Service - Gaps

3.3.4.2 Controller- Pilot Data Link Communications (CPDLC)

CPDLC has been identified as the means for automated delivery of hazardous weather alerts to the cockpit. However, it is unlikely that this capability can be implemented on VDL-2 (which is the only datalink available in the 2007 time frame). The gap that exists in this case is one of time, not technology. It is unlikely that the NEXCOM implementation of VDL-3 for data can be accelerated into the 2007 time frame. In the interim, however, research could be performed to determine if a satisfactory priority message scheme could be developed and integrated into the VDL-2 link. Also, standards work can be performed to add hazardous weather messages to the CPDLC message set for use when VDL-3 is implemented. Finally, research could be performed to promote a standard for a cockpit voice synthesis capability that would provide audio delivery of CPDLC messages to the pilot.

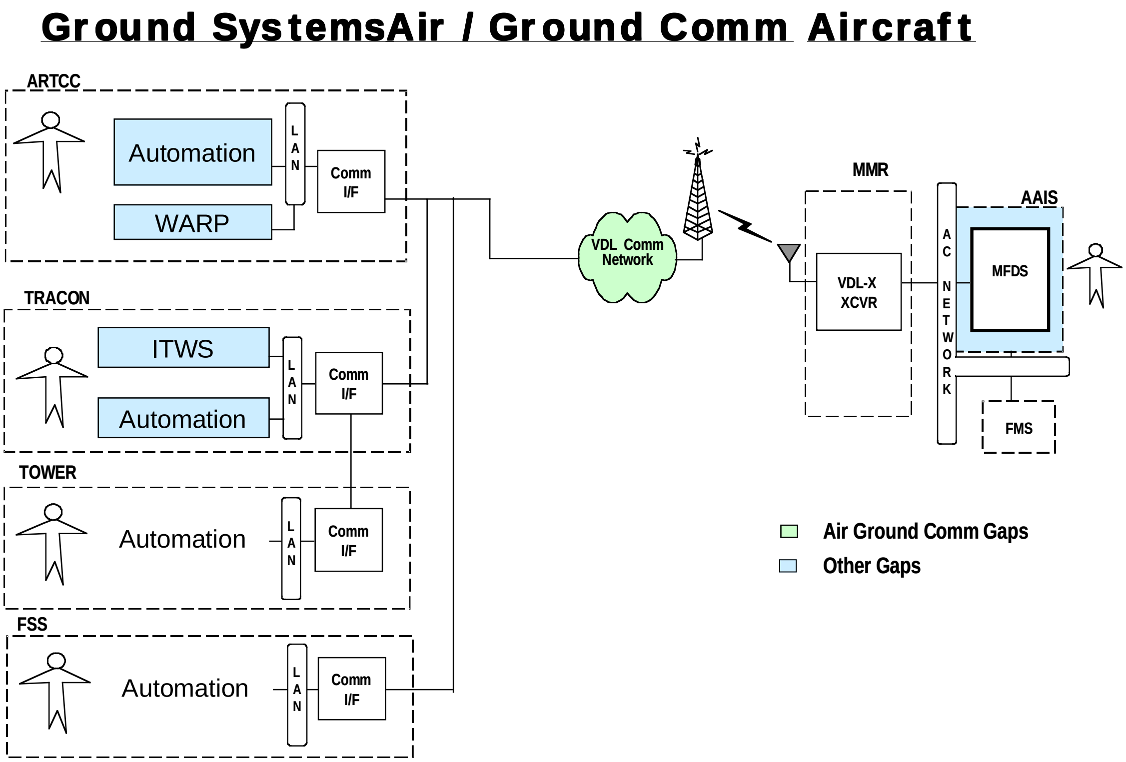

Figure 3.3-9. CPDLC Controller/Pilot Data Link Communications - Gaps

3.3.4.3 CPC Air/Ground Voice Communications

NEXCOM provides the voice communications capability for the NAS. From a technology gap standpoint, NEXCOM/VDL-3 has the implementation time line problems mentioned in the CPDLC gaps above. There are concerns, however, in the area of voice digitization. Further research can be performed to improve the digital voice compression techniques at rates of 4800 bps. Also, improved speech recognition systems are being deployed in a number of commercial areas. Speech recognition technology will continue to be used in automation systems. The research and development focus should be to reduce the effects of background noise which leads to errors in every environment[3].

[3] **Joel Stratte-McClure, Continental Magazine, March 2000**

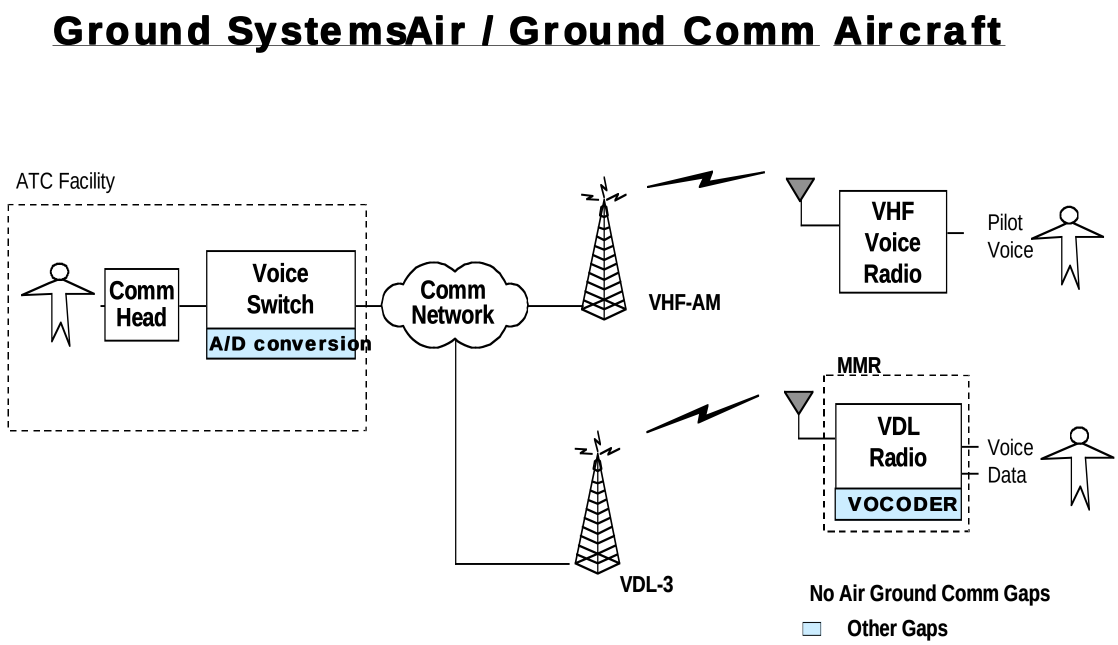

Figure 3.3-10. CPC Air/Ground Voice Communication - Gaps

3.3.4.4 Automated Meteorological Reporting (AUTOMET)

From an air/ground communications standpoint, work is currently underway to develop standards for the implementation of AUTOMET. From an avionics perspective, with this in mind it is essential to ensure that the data delivered from an AUTOMET sensor be accurate at all times in order to maintain the integrity of the forecast model.

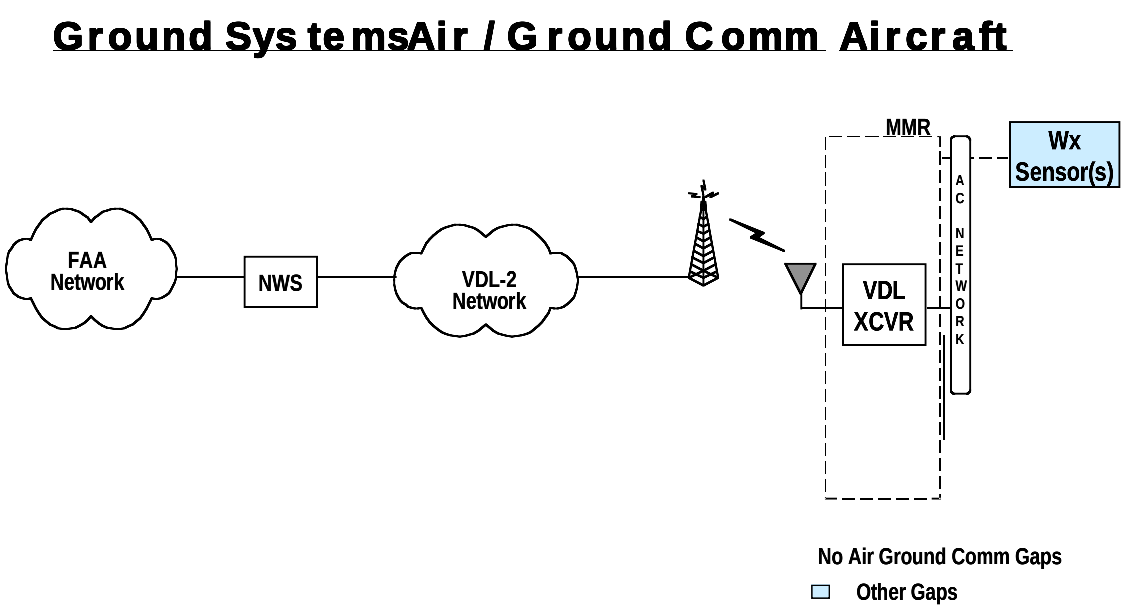

Figure 3.3-11. Automated Meteorological Transmission (AUTOMET)

In summary, the most significant communications technology gaps for AWIN reside in the potential of developing satellite communications capabilities that can be integrated onto all aircraft platforms.

3.4 AWIN Communication Architecture Transition

This section describes the primary schedule of activities that we have identified to support a transition from today's communication architecture to an AWIN communications architecture in the 2007 time frame. The activities identified were grouped into ground, air, and avionics communications and then were further divided into research, standards, and systems areas with certification also identified for avionics. The AWIN communication architecture schedule is shown in figure 3.4-1. We will discuss these activities for each technical concept.

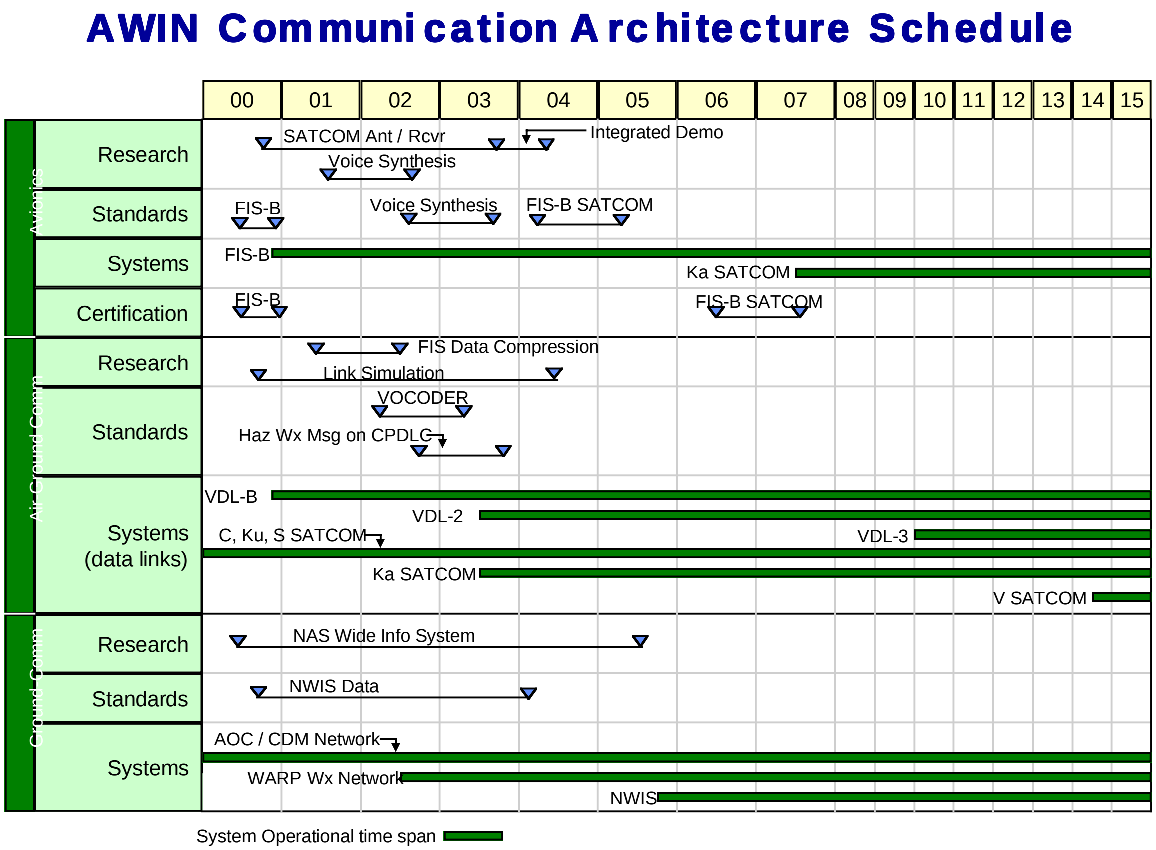

Figure 3.4-1. AWIN Schedule

Flight Information Services

An FIS-B MASPS (Minimum Aviation System Performance Standards) is being drafted by RTCA SC-195 with an anticipated completion date near the end of calendar year 2000. It is in this time frame that the service providers will begin to provide service via their preferred VDL-B technology in selected areas of the NAS. Deployment of FIS throughout the NAS will proceed based on the demand for service. If the demand for service and the amount of FIS data continue to grow as anticipated and the deployment of next generation Ka band satellites also continues, there will most likely be a market for aero-mobile SATCOM FIS. In order to support a deployment of satellite based FIS in 2007, research on aircraft suitable antennas, receivers, encoding schemes, etc must begin in the near term. This research would culminate in an integrated demonstration for each class of aircraft in the first and second quarters of FY2004. Additionally, on the ground, research and standards development is required to establish the data structure for the NAS-wide information system. Establishment of the NWIS will be the primary driver for the sharing of additional data with the aircraft.

Controller Pilot Data Link Communications

For CPDLC, research should begin in the near term to determine if a standard can be developed for the timely, automated distribution of hazardous weather alerts over VDL-2. Also, near term research should be conducted on the application and use of voice synthesis in the cockpit for audio delivery of CPDLC messages.

CPC Voice Communications

While VCODER standards exist today, there is a need for a next generation of standards that concentrate on the elimination of background noise, especially in the cockpit. Additionally, efforts should be focused on establishing compatibility of digitization schemes between the avionics and ground to ensure high quality voice communication.

AUTOMET

Research should continue on aircraft weather sensors with an emphasis on the development of sensors that support the ability to remotely determine accuracy and that do not require calibration by the aircraft owner/operator. Link simulations should be conducted to determine the peak performance requirements for download of sensor data.

4 Communication Loading Analysis

4.1 Air-Ground Weather Communications

The overall approach to the air-ground weather communications load analysis is illustrated in Figure 4.1-1 and presented in detail in the following sections. Air-ground weather communications service requirements are addressed in Section 4.2. Air-ground weather messages and messages per flight are calculated in Section 4.3. Voice message traffic per flight is calculated in section 4.4. Projections for the peak number of flights in 2007 are estimated and the total traffic load is calculated in Section 4.5.

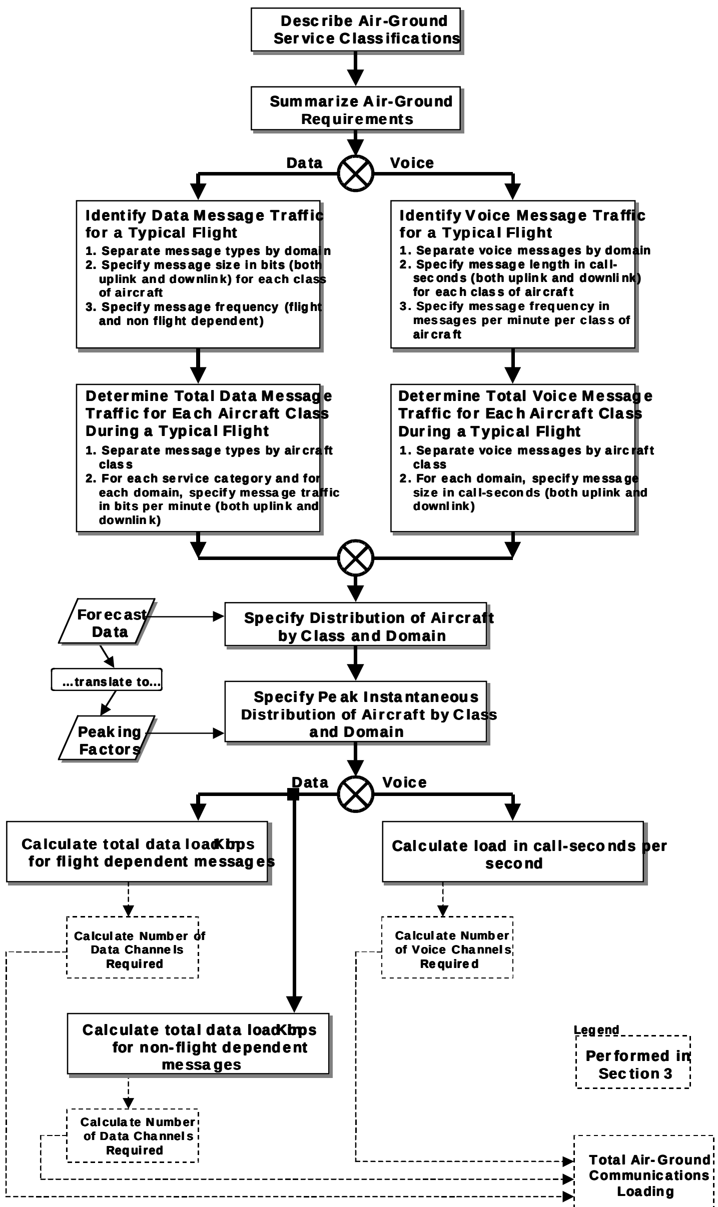

Figure 4.1-1. Communications Load Analysis Method

In this analysis, the term air-ground is used when the direction of the transmission is not relevant. Whenever direction is important, the terms uplink (ground-to-air) and downlink (air-to-ground) are used. The terms message and message traffic are used when the distinction between voice and data messages is not relevant. Otherwise, the term voice message or data message is used.

Throughout the analysis, communications traffic is separated by airspace domains and classes of aircraft. The domains consist of airport, terminal, en route, and oceanic. The three classes of aircraft are low-end general aviation (Class 1), high-end general aviation and commuter aircraft (Class 2), and commercial carriers (Class 3). The classification by domain and airspace gives a more precise traffic load estimate since the number, frequency, and type of message in many cases depends on where the aircraft is and what type of equipage it has. Also, by separating traffic loads according to domain, the air-ground communication architecture can be optimized to meet unique regional requirements. For this analysis, the aircraft classes and domains are defined as shown in Table 4.1-1 and Table 4.1-2.

Table 4.1-1. Aircraft Classes

Class of Aircraft	Definition and Comment
Class 1	Operators who are required to conform to FAR Part 91 only, such as low-end General Aviation (GA) operating normally up to 10,000 ft. This class includes operators of rotorcraft, gliders, and experimental craft and any other user desiring to operate in controlled airspace below 10,000 ft. The primary distinguishing factor of this class is that the aircraft are smaller and that the operators tend to make minimal avionics investments.
Class 2	Operators who are required to conform to FAR Parts 91 and 135, such as air taxis and commuter aircraft. It is likely that high-end GA and business jets and any other users desiring to operate in controlled airspace will invest in the necessary avionics to be able to achieve the additional benefits.
Class 3	Operators who are required to conform to FAR Parts 91 and 121, such as Commercial Transports. This class includes passenger and cargo aircraft and any other user desiring to operate in controlled airspace. These users will invest in the avionics necessary to achieve the additional benefits.

Table 4.1-2. Airspace Domains

Domain	Definition and Comment*
En route	Airspace in which en route air traffic control services are normally available. The average duration in this domain is 25 minutes per en route center.
Terminal	Airspace in which approach control services are normally available. The average duration in this domain is 10 minutes.
Airport	Airspace, including, runways and other areas used for taxiing, takeoff, and landing, in which tower control services are normally available. The average duration in this domain is 10 minutes.
Oceanic	Airspace over the oceans of the world, considered international airspace, where oceanic separation and procedures per the International Civil Aviation Organization are applied. The average duration in this domain is 180 minutes.

Average duration of flights are taken from *Aeronautical Spectrum Planning for 1997-2010*, RTCA/DO-237, January 1997, p. F-4.

All message traffic is assigned to technical concept categories to simplify calculations and provide insights that guide the architectural solutions presented in Chapter 3. The only two categories used for weather messages are shown in Table 4.1-3 and represent logical groupings of messages based on application and similar service requirements. Table 4.1-4 shows the estimated aircraft population in each class that is equipped for a particular technical concept. The percentages in Table 4.1-4 were developed using FAA forecasts and engineering judgement. The values are only approximate but have been specified to the nearest percent to maintain internal consistency. The percentages were assumed to be the same for FIS and AUTOMET.

Table 4.1-3. Air-Ground Technical Concept Classifications

Category.	Technical Concept	Description of Concept
1	Flight Information Services (FIS)	Aircraft continually receive Flight Information to enable common situational awareness
8	Automated Meteorological Reporting (AUTOMET)	Aircraft report airborne weather data to improve weather nowcasting and forecasting

Table 4.1-4. Percent of Aircraft Equipped for Each Technical Concept in 2007

Technical Concept	Class 1	Class 2	Class 3
FIS	16%	22%	24%
AUTOMET	16%	22%	24%

4.2 Air-Ground Communications Service Requirements

Communications service requirements include priority, availability and restoral times, call setup time, latency, and interfaces. Availability and restoration times depend on NAS priority level, which in turn drive the level of link redundancy needed. Table 4.2-1 shows requirements for the two technical concepts of interest.

Table 4.2-1. Air-Ground Service Requirements

Technical Concept.	Priority	Availability Restoration Time	Call Setup Time	Latency End to End	Aircraft Interface
FIS	Routine	0.99 1.68 hour	≤10 sec	~10 sec	FAA NWIS Network
AUTOMET	Routine	0.99 1.68 hour	≤ 30 sec	~10 sec	Commercial Service Provider

FIS and AUTOMET messages are considered to have routine priority. The NAS System Requirements Specification defines routine services as those which, if lost, would not significantly degrade the capability of the NAS to exercise safe separation and control of aircraft. For routine services the availability goal is 0.99 and the goal for service restoral time is 1.68 hours.

Coverage requirements for air-ground services are assumed to be:

- Fully redundant coverage for continental United States (CONUS), Hawaii, Alaska, Caribbean islands, Canada, Mexico, and Central and South America.
- Single coverage over the Pacific and Atlantic Ocean regions (redundant coverage is assumed to be provided by other CAAs and by commercial service providers
- Single coverage over the polar regions

All voice traffic in 2007 is assumed to be analog.

These service requirements are used in the load analysis for purposes of grouping messages with similar service and delivery requirements. They are of greater importance, however, in selecting communications link technologies and in the development of the overall architecture presented in Section 3.

4.3 Air-Ground Data Message Traffic Requirements

Information on weather message sizes and frequencies came from a number of sources. A unique message identifier (Msg ID), shown in Table 4.3-1, is assigned to the various messages to simplify later reference. In most cases, message types represent specific messages with a constant length and repetition rate. In some cases, however, message types are merely representatives of the type, and the characteristics are simply an average.

Table 4.3-1. Message Types and Message Type Identifiers

Message Type Identifier	Message Type
M4	Aircraft Originated Meteorological Observations
M13	Arrival ATIS
M14	AUTOMET
M15	Convection
M16	Delivery of Route Deviation Warnings
M17	Departure ATIS
M18	Destination Field Conditions
M20	En Route Backup Strategic General Imagery
M21	FIS Planning – ATIS
M22	FIS Planning Services
M26	General Hazard
M27	Icing
M28	Icing/ Flight Conditions
M29	Low Level Wind Shear
M35	Radar Mosaic
M37	Surface Conditions
M39	Turbulence
M40	Winds/ Temperature
M43	Aircraft Originated Ascent Series Meteorological Observations
M44	Aircraft Originated Descent Series Meteorological Observations

Each weather message type is mapped to an aircraft class and airspace domain based on information in the reference source and expert knowledge. The messages are further assigned to one of the technical concept categories to simplify subsequent calculations and facilitate communications architecture decisions.

Some message types are extremely large and compression is assumed in order to reduce communications loads. The compression ratios are shown in Table 4.3-2. In some cases, the same message is sent with different compression ratios because the required resolution is not the same in all domains (e.g., M15 and M28). Note that all traffic data presented in this chapter is compressed according to Table 4.3-2 and no further compression should be applied.

Throughout the analysis voice and data traffic are treated separately to deal with any unique requirements they impose on the communications architecture.

Table 4.3-2. Data Compression Factors Used (1:1 assumed for all other messages)

Domain	Msg ID	Compression*
Terminal Tactical	M18 M20 M27 M29 M37	10:1 10:1 10:1 10:1 20:1
Terminal Strategic	M15 M28 M35	50:1 50:1 10:1
En Route Tactical	M39	50:1
En Route Near Term Strategic	M15 M26 M28 M37 M39	20:1 20:1 20:1 20:1 20:1
En Route Far Term Strategic	M15 M26 M28	50:1 50:1 50:1

**Data Communications Requirements, Technology and Solutions for Aviation Weater Information Systems, Phase I Report, Aviation Weather Communications Requirements*, Lockheed Martin Aeronautical Systems

Data message tables are developed for each class of aircraft based on the particular set of weather messages required by that class in a given domain. Note that frequency units are expressed in terms of messages per flight or messages per minute per flight, depending on the nature of the communications. For messages that occur on a periodic basis and are independent of the number of aircraft, frequencies are expressed in terms of messages per minute. These messages are listed in a separate table (see Table 4.3-4) and only added the total communications load after per-flight calculations are completed. The largest common unit used to express message frequencies and flight times was a minute; this time unit was chosen to express weather message traffic in consistent terms for all calculations and to avoid confusing traffic loads with channel data rates.

4.3.1 Data Message Traffic per Flight

Data message traffic by flight for each class of aircraft is summarized in Table 4.3-3. This table does not represent peak traffic, but rather the expected traffic with departures and arrivals evenly distributed within each domain. All message sizes are in bits.

Table 4.3-3. Data Message Traffic For All Classes of Aircraft (flight dependent)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
FIS	M17	En Route	1 msg/flt	3200	1 msg/flt	64
	M21	Terminal	1 msg/flt	400	1 req/flt	56
	M22	Airport	1 msg/10 sec	2100	1 req/flt	64
	M22	Terminal	1 msg/10 sec	2000	6 req/flt	64
	M22	En Route	1 msg/10 sec	2000	4 req/flt	64
	M28	En Route	1 msg/flt	45000	N/A	N/A
AUTOMET	M14	Airport	N/A	N/A	10 msg/flt	430
	M14	Terminal	N/A	N/A	3 msg/minute	430
	M14	En Route	N/A	N/A	1 msg/15 minutes	430
	M4	Terminal	1 msg/flt	56	1 msg/5 minutes	1760

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)	Frequency	Downlink Size (bits)
AUTOMET	M4	En Route	1 msg/flt	56	1 msg/5 minutes	1760
	M43	Terminal	1 msg/flt	56	3 msg/min	512
	M43	En route	1 msg/flt	56	1 msg/6 min	2152
	M44	En Route	1 msg/flt	56	1 msg/2min	3544

* Compressed per Table 4.3-2

Non-flight dependent products shown in Table 4.3-4 usually are large messages that are identical for all recipients. They can be sent on a periodic basis and the number of times they are sent is not dependent on the number of flights. The message characteristics are assumed to be the same for all classes and in all domains.

Table 4.3-4. Non Flight Dependent Data Message Traffic (all aircraft classes)*

Technical Concept	Msg. ID	Domain	Frequency	Uplink Size (bits)
FIS	M15	En Route	4 products/60 minutes	252000
	M15	En Route	6 products/60 minutes	306000
	M15	Terminal	6 products/60 minutes	252000
	M18	Terminal	60 products/60 minutes	1300
	M20	En Route	4 products/60 minutes	2800000
	M26	En Route	2 product/60 min	144000
	M26	En Route	6 products /60 min	350000
	M27	Terminal	60 products /60 min	5510
	M28	En Route	6 products /60 min	219000
	M28	En Route	2 products/60 min	27000
	M40	En Route	1 product/60 minutes	54000
	M40	En Route	6 product/60 minutes	262500
	M29	Terminal	6 products/60 min	480
	M35	Terminal	31 products/60 minutes	7350
	M37	En Route	4 products/60 minutes	28800
	M39	En Route	1 product/60 minutes	27000
	M39	En Route	6 product/60 minutes	131000
	M39	En Route	4 product/60 minutes	252000

*Note that all downlink traffic is flight dependent; compressed per Table 4.3-2

4.3.2 Data Message Load Per Flight

In order to convert messages per flight to an actual data load, several assumptions are required regarding the duration of flights communications protocol overheads, and message characteristics:

- ATN protocol overheads are applied to all connection oriented messages, i.e., AUTOMET messages and flight dependent FIS messages.
- The ATN protocol network layer overhead varies according to message context and message size; the actual overhead spans a wide range of documented values. RTCA/DO-237, for example, uses a protocol overhead of 136% for uplink messages and 1376% for downlink messages. (These values are biased toward the maxima that can be expected; the average overhead on downlink traffic is likely to be far less in practice.) This analysis assumes an average network overhead of 20% in both directions for FIS and AUTOMET messages. This figure is in general agreement with the results of ARINC overhead predictions for various AOC messages.

- Non-flight dependent FIS messages include a network layer overhead of 10% for error detection and synchronization.
- A physical layer overhead of 50% is assumed on all data messages (RTCA/DO-237).
- Modulation efficiency for D8PSK is assumed to be 1.25 bps per Hertz (RTCA/DO-237).
- The average time a flight spends in each airport domain is 10 minutes (RTCA/DO-237).
- The average time a flight spends in each terminal domain is 10 minutes (RTCA/DO-237).
- The average time a flight spends in each en route domain is 25 minutes per center; an average flight spans two centers.
- The average time a flight spends in the oceanic domain is 180 minutes.
- Only AUTOMET message types M43 and M44 are included in the data communications loading calculations; these messages are assumed to contain all the information found in other AUTOMET messages that are smaller in size. Message sizes and frequencies are based on the 1999 draft RTCA Minimum Interoperability Standard for AUTOMET.
- 8 bits per character is used to convert messages size in characters to message size in bits for AUTOMET messages M43 and M44; all other messages are given as bits in the source documents used.
- AUTOMET traffic is suppressed in the airport domain to reduce channel requirements; the data is highly redundant and duplicates what is available from fixed airport weather sensors.

These assumptions are used to convert data message traffic in Table 4.3-3 into bits per flight per minute for each technical concept and class of aircraft. To get bits per minute per flight, the message size in bits is multiplied by the frequency in messages per minute. If the messages are on a per flight basis, the conversion requires multiplying the message size in bits times the number of messages per flight in a particular domain divided by the time a flight spends in that domain to obtain bits per minute per flight as shown in Table 4.3-5, Table 4.3-6, and Table 4.3-7.

Table 4.3-5. Data Message Traffic for Aircraft Class 1 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	2903.0	1.5	2774.0	10.1	5052.2	2.9
AUTOMET	N/A	N/A	1.3	353.9	1.0	490.9

*Compressed per Table 4.3-2

Table 4.3-6. Data Message Traffic for Aircraft Class 2 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	3991.7	2.0	3814.3	13.9	6946.8	4.1
AUTOMET	N/A	N/A	1.8	486.6	1.4	675.0

*Compressed per Table 4.3-2

Table 4.3-7. Data Message Traffic for Aircraft Class 3 (bits per min per flight)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	4354.6	2.2	4161.0	15.2	7578.3	4.4
AUTOMET	N/A	N/A	1.9	530.8	1.5	736.4

*Compressed per Table 4.3-2

4.3.3 Non Flight Dependent Data Message Traffic

Many FIS messages are not dependent on the number of flights or the instantaneous airborne count. For messages that do not increase in number as the number of aircraft increase, the message size in bits is multiplied by the frequency in messages per minute and aggregated in Table 4.3-8.

Table 4.3-8. Non-Flight Dependent Data Message Traffic (bits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	38,154.1	0.0	391,695.3	N/A

*Compressed per Table 4.3-2

4.3.4 Oceanic Data Message Load Per Flight

In the oceanic domain, weather message traffic consists of FIS and AUTOMET as shown in Table 4.3-9. It is assumed that users in 2007 will want to receive the full complement of en route messages in the oceanic domain, if the communications links can support it. Using the same messages and message frequencies in the oceanic domain would provide seamless communications when transiting the NAS. Only Class 3 aircraft are included since the other classes are used primarily for domestic flights.

Table 4.3-9. Oceanic Data Message Traffic for Aircraft Class 3 (bits per min per flight)*

Technical Concept	Airport		Terminal		Oceanic	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	N/A	N/A	6,912.0	0.0
AUTOMET	N/A	N/A	N/A	N/A	0.9	3,068.2

*Compressed per Table 4.3-2

4.4 Voice Traffic

In 2007, the only weather related voice traffic is assumed to be CPC advisories. It is assumed that voice will be used in the airport domain by all aircraft classes but CPDLC will be used in lieu of voice in the terminal and en route domains by aircraft that are suitably equipped.

Table 4.4-1. Voice Message Traffic in 2007 (call-seconds)

Message	Domain	Class	Uplink	Downlink	Msgs. per Flight
CPC Advisories	En Route	1	20 sec	5 sec	1/flt
CPC Advisories	En Route	2	10 sec	5 sec	1/flt
CPC Advisories	En Route	3	10 sec	5 sec	1/flt

The total voice traffic per flight is calculated by multiplying the duration of the voice message by the number of times the message occurs and dividing by the time spent in the domain. The results are summed for each domain and class of aircraft to get the total per flight requirements then discounted based on the percentage of aircraft in each class that will be sending this information via CPDLC.

Table 4.4-2. CPC Voice Message (call-seconds per min per flight)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	N/A	N/A	N/A	N/A	0.7	0.2
2	N/A	N/A	N/A	N/A	0.3	0.2
3	N/A	N/A	N/A	N/A	0.3	0.1

4.5 Traffic Load Analysis

4.5.1 Flight Forecasts

The average traffic load is developed from the per flight message traffic multiplied by the expected number of flights in 2007. Communications links, however, are generally designed for peak loads to avoid increased delays or blocking when traffic is heaviest. Peak flights by domain for 1998 are therefore projected out to 2007 to estimate the peak load. The projections shown in Table 4.5-1 represent a 12.6% increase in operations between 1998 and 2007 for the aircraft classes of interest. FAA forecasts for terminal area itinerant aircraft operations are used because they correspond closely to the number of flights and are available from FAA forecast data by class of aircraft. For simplicity, it is assumed that the percent growth within each aircraft class and domain is the same as the percent growth in total aircraft operations.

Table 4.5-1. Peak Number of Flights (Aircraft) by Domain in 2007

Year	Operations*	Airport	Terminal	En Route
1998	73,169,228	154	110	400
2007	82,392,277	173	125	450

*APO Terminal Area Forecast Summary Report, TAF System Model

Applying the forecast distribution of operations for each class of aircraft to the number of flights in each domain provides the approximate distribution of flights by class and domain for 2007 as shown in Table 4.5-2.

Table 4.5-2. Estimated Peak Distribution of Flights by Class and Domain in 2007

Class	Operations*	Airport	Terminal	En Route
1	48,452,403	102	73	265
2	15,629,983	33	24	85
3	18,309,891	38	28	100
Total	82,392,277	173	125	450

*APO Terminal Area Forecast Summary Report, TAF System Model

4.5.2 Data Traffic Load

Multiplying the peak number of flights in Table 4.5-2 by the messages per flight in Table 1.3-5, Table 1.3-6, and Table 1.3-7 results in the estimated peak loads shown in Table 4.5-3, Table 4.5-4, and Table 4.5-5.

Table 4.5-3. Peak Data Message Traffic for Aircraft Class 1 in 2007 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	296.1	0.2	282.9	1.0	515.3	0.3
AUTOMET	N/A	N/A	0.1	36.1	0.1	50.1

*Compressed per Table 4.3-2

Table 4.5-4. Peak Data Message Traffic for Aircraft Class 2 in 2007 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	131.7	0.1	125.9	0.5	229.2	0.1
AUTOMET	N/A	N/A	0.1	16.1	0.0	22.3

*Compressed per Table 4.3-2

Table 4.5-5. Peak Data Message Traffic for Aircraft Class 3 in 2007 (kilobits per min)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	165.5	0.1	158.1	0.6	288.0	0.2
AUTOMET	N/A	N/A	0.1	20.2	0.1	28.0

*Compressed per Table 4.3-2

Combining the peak data message load for each aircraft class and converting to kilobits per second provides the aggregate load shown in Table 4.5-6. The table shows that addressing FIS messages to individual aircraft in the NAS would require a peak uplink bandwidth of 9.9 kbps in the busiest airport domains, 9.4 kbps in the busiest terminal domains, and 17.2 kbps in the busiest en route domains. The largest AUTOMET load is1.7 kbps in the peak terminal domain.

Table 4.5-6. Combined Peak Data Message Traffic for All Aircraft Classes in 2007 (kilobits per second)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	9.9	N/A	9.4	N/A	17.2	N/A
AUTOMET	N/A	N/A	0.0	1.2	0.0	1.7

*Compressed per Table 4.3-2

Non flight dependent traffic loads are shown in Table 4.5-7 for national coverage. The numbers in Table 4.5-7 are calculated by dividing the traffic in Table 1.3-8 by 60 x 1000 to express the load in kilobits per second. From this table it can be seen that the FIS en route peak load would require a 6.5 kbps uplink channel and the peak terminal load would require a 0.6 kbps uplink channel.

Table 4.5-7. National Non-Flight Dependent peak Data Message Traffic for All Aircraft Classes in 2007 (kilobits per sec)*

Technical Concept	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	0.0	N/A	0.6	N/A	6.5	N/A

*Compressed per Table 4.3-2

4.5.3 Oceanic Traffic Load

Peak oceanic flights are estimated based on peak hour contacts by Oakland and New York centers. Of the two, New York is slightly higher with 84 flights en route in the peak hour in 2000. Assuming 12.6% growth by 2007, the messages rates per flight in Table 1.3-9 are multiplied by 95 peak flights in 2007 and divided by 60*1000 to get kilobits per second. The table shows that a 21.5 kbps uplink is sufficient for peak loads.

Table 4.5-8. Total Oceanic Data Message Traffic in 2007 (kilobits per second)*

Technical Concept	Airport		Terminal		Oceanic	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
FIS	N/A	N/A	N/A	N/A	10.9	0.0
AUTOMET	N/A	N/A	N/A	N/A	0.0	4.9

*Compressed per Table 4.3-2

4.5.4 Voice Traffic Load

Peak CPC voice weather advisory traffic is shown in Table 4.5-9. The number of call-seconds per minute per flight from Table 4.4-2 is multiplied by the peak number of flights in Table 4.5-2 and then divided by 60 seconds per minute to get channel occupancy in call-seconds per second. The total for each domain represents the number of full-period uplink or downlink analog voice channels required. To minimize the chance of all channels being in use at the same time, extra capacity can be added to the system. Assuming a multiserver queue with exponentially distributed call durations as a worst-case model for air-ground communications, the number of channels needed for a given probability of blocking can be calculated. In this analysis, it is assumed that there should be no more than one chance in five of finding all channels busy. Under peak traffic conditions with a 0.2 probability of all channels being busy, it is seen that the busiest en route domain in 2007 requires 6 voice channels. It is assumed that voice weather advisories do not occur in the other domains.

Table 4.5-9. Peak CPC Voice Messages in 2007 (call-seconds/second)

Class	Airport		Terminal		En Route	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1	N/A	N/A	N/A	N/A	3.0	0.8
2	N/A	N/A	N/A	N/A	0.4	0.2
3	N/A	N/A	N/A	N/A	0.5	0.2
Total	N/A		N/A		5.2	
Voice Channels Required (P=0.2)	N/A		N/A		6	

5 Communications Links Analysis

This section provides the technical detail of the data links available for the 2007 architecture. Much of this information is also presented in the Task 9 Report, *Characterize the Current and Near-Term Communications System Architectures*, which provides additional information on applications, standards, protocols, and networks. The links discussed in this section are:

- Voice - DSB-AM
- VHF Digital Link Mode 2 (VDLM2)
- VHF Digital Link Mode3 (VDLM3)
- VHF Digital Link Broadcast (VDL-B)
- Mode S
- Universal Access Transceiver (UAT)
- Example Geosynchronous (GEO) Satellite (Recommended SATCOM)
- Example Medium Earth Orbit (MEO) Satellite
- Example Low Earth Orbit (LEO) Satellite
- High Frequency Data Link (HFDL)

5.1 Standard Description Template

Each link is characterized according to section 4.6.1 of the Task Order and organized using the following template.

CHARACTERISTIC	Segment	DESCRIPTION
System Name		Name
Communication type	R/F Ground	HF, VHF, L-Band, SATCOM …
Frequency/Spectrum of Operations	R/F Ground	Frequency
System Bandwidth Requirement	R/F Ground	Bandwidth for channel and system
System and Channel Capacity	R/F	Number of channels and channel size
Direction of communications	R/F	Simplex, broadcast, duplex….
Method of information delivery	R/F Ground	Voice, data, compressed voice
Data/message priority capability	R/F Ground	High, medium, low
System and component redundancy	R/F Ground	
Physical channel characteristics	R/F	Line of sight (LOS), other
Electromagnetic interference	R/F	Text description
Phase of Flight Operations	Ground	Pre-flight, departure, terminal ….
Channel Data Rate	R/F Ground	Signaling rate
Robustness of channel and system	R/F	Resistance to interference, fading…
System Integrity	R/F Ground	Probability
Quality of service	R/F Ground	Bit error rate, voice quality
Range/coverage	R/F Ground	Oceanic, global, regional…
Link and channel availability	R/F Ground	Probability
Security/encryption capability	R/F Ground	Text description
Degree/level of host penetration	R/F	Percentage or class of users
Modulation scheme	R/F	AM, FM, D8PSK,….
Access scheme	R/F	CSMA, TDMA, ….
Timeliness/latency, delay requirements	R/F Ground	Delay
Avionics versatility	R/F	Application to other aircraft
Equipage requirements	R/F	Mandatory, optional
Architecture requirements	R/F Ground	Open System or proprietary
Source documents		References

Integrity is the ability of a system to deliver uncorrupted information, and may include timely warnings that the information or system should not be used. Integrity is provided by the application, transport and network layers (rather than the link and physical layers), and is usually specified in terms of the probability of an undetected error. The integrity values in the following link descriptions thus reflect service integrity requirements rather than "link integrity" requirements. The only meaningful measure of "link integrity" is a bit error rate, which is shown under quality of service.

Comm Link	System integrity (probability)
Voice DSB-AM	No integrity requirement for 2007 voice services
VDL Mode 2	CPCLC and DSSDL will be ATN compliant services and require that the end -to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message be less than or equal to $10E^{-8}$ per message
VDL Mode 3	No integrity requirement for 2007 voice services
VDL-B	Some FIS products may require that the end-to end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message be less than or equal to $10E^{-8}$ per message.
Mode-S	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has be supplied to the ADS-B system. ADS-B system integrity is $10E^{-6}$ or better on a per report basis. [Note: Due to constraints imposed by the Mode-S squitter message length, multiple messages must typically be received before all required data elements needed to generate a particular ADS-B report are available.]
UAT	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has be supplied to the ADS-B system. ADS-B system integrity is $10E^{-6}$ or better on a per report basis. Currently, the UAT worst-case overall undetected error probability for an ADS-B message is $3.7x10E^{-11}$, which exceeds the minimum requirement. [Note: For UAT, ADS-B messages map directly (one-to-one correspondence) to ADS-B reports; they are not segmented as they are in Mode-S ADS-B.]
Inmarsat-3	No integrity requirement for 2007 data services
GEO Satellite	Some FIS products may require that the end-to-end system probability of not detecting a mis-delivered, non-delivered, or corrupted 255-octet message be less than or equal to $10E^{-8}$ per message
MEO Satellite	No integrity requirement for 2007 data services
ICO Global Satellite	No integrity requirement for 2007 data services
Iridium Satellite	No integrity requirement for 2007 voice services
HFDL	No integrity requirement for 2007 data services

5.2 Near-Term Links Available

5.2.1 VHF DSB-AM

Virtually all air traffic control communications are currently based on the VHF, double-side band amplitude modulated (DSB-AM) radio. DSB-AM has been used since the 1940s, first in 100 kHz channels, then in 50 kHz channels, and now 25 kKz channels. Recently, Europe has further reduced channel spacing to 8.33 kHz channels in some air space sectors due to their critical need for more channels. In the United States, the FAA provides simultaneous transmission over UHF channels for military aircraft. In the oceanic domain beyond the range of VHF, aircraft use HF channels. Studies have shown that controller workload is directly correlated to the amount of voice communications required. Voice is subject to misinterpretation and human error and has been cited as having an error rate of 3% and higher. With the introduction of ACARS, AOC voice traffic dropped significantly although it is still used.

Table 5.2-1. Analog Voice/VHF DSB-AM Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Analog voice/VHF double sideband (DSB)—amplitude modulated (AM)**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	Leased telephone channels
Frequency/ Spectrum of Operations	RF	117.975 MHz—137 MHz
System Bandwidth Requirement	RF	Nominal 3 kHz per channel with audio input 350 - 2,500 Hz 760 channels total in VHF band @ 25 kHz spacing/channel
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Nominal 3 kHz per channel with audio input 350 - 2,500 Hz 760 channels total in VHF band @ 25 kHz spacing/channel System is constrained by frequency allocation, not technical limits. Expansion to 112 MHz has been discussed if radionavigation systems are decommissioned.
	Ground	Telephone line per assigned radio frequency
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Simplex - Transmission or reception on a single frequency but not simultaneously.
	Ground	Voice telephone lines are duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Voice
	Ground	Voice
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	N/A
	Ground	N/A
System and component redundancy requirement (1/2, 1/3, etc):	RF	Airborne - One unit required for GA, two units for air carrier. Redundancy: GA typically equips with two units (1:1); air carrier equips with three units (1:2).
	Ground	1:1 plus some overlap of ground stations
Physical channel characteristics (LOS, OTH, etc.):	RF	Line of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics:	RF	RTCA DO-160C, Sections 15, 18, 19, 20, and 21.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	3 kHz
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Voice communications are error prone and highly variable. An error rate of 3% has been measured in high activity sectors.
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	VHF voice communications are generally considered poor due to system and background noise. (The human ear is VERY good at puling voice out of a noisy AM signal.) A standard voice quality metric has not been applied.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 250 nm at 30,000 feet 100 nm at 5,000 feet Coverage: United States including the Gulf of Mexico.
Link and channel availability	RF	Exceeds 99.7%
Security/ encryption capability	RF	N/A

CHARACTERISTIC	SEGMENT	DESCRIPTION
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	All commercial, all military and most GA aircraft equipped. All aircraft participating in IFR airspace are required to equip. Approximately 20,000 GA aircraft use only unrestricted airspace and do not equip with a radio.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Double sideband—Amplitude Modulation (DS-AM)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Normal signal propagation delay
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	System	Respond to 75% of calls within 10 seconds and 94% of calls within 60 seconds
	System	No measured data. Air Traffic Controllers determine access and priority based on traffic and situation.
Avionics versatility (applicability to other aircraft platforms)	Avionics	Any aircraft equipped with VHF transmitter and receiver.
Equipage requirements (mandatory for IFR, optional, primary, backup,	Avionics	Mandatory for IFR flight operations; not required in uncontrolled airspace.
	Ground	Ground stations required for coverage.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications, etc.)	RF/Avionics	Signal in space characteristics are set by National and International standards. Avionics are developed by vendors with proprietary designs. Some integration with navigation.
	Ground	Vendors provide ground communications using proprietary hardware/software designs and commercial telecommunications standards.
Source documents		Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; ARINC Quality Management Reports, Air/Ground Voice Performance

5.2.2 VDL Mode 2

VDL Mode 2 is a 1990's concept for aeronautical data link. It has been designed by the international aviation community as a replacement for ACARS. Many of the limitations of ACARS have been overcome in the VDL Mode 2 system. The best known improvement is the increase in channel data rate from the ACARS 2.4 kbps rate to a 31.5 kbps rate. The improved rate is expected to increase user data rates ten to 15 times over the current ACARS. The variation is dependent upon user message sizes, channel loading assumptions, and service provider options. VDL Mode 2 can carry all message types carried by ACARS plus Air Traffic Service messages such as CPDLC, which require performance levels of latency and message assurance not possible with ACARS.

VDL Mode 2 is a subnetwork in the Aeronautical Telecommunication Network (ATN). ATN has been adopted by ICAO to provide a global air/ground and ground/ground network for all aviation related traffic. ATN addresses both the communications aspects and the applications.

Table 5.2-2. VDL Mode 2 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**VHF Digital Link Mode 2** (VDL Mode 2)
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	ARINC Data Network System (ADNS) & ARINC Packet Network (APN)
Frequency/ Spectrum of Operations		136.975MHz, 136.950MHz, 136.925MHz, 136.900MHz currently approved for VDL in international frequency plans. The 136.500 - 137.0 MHz band (20 channels) is potentially assignable to VDL Mode 2 in the U.S. Additional frequencies are based on availability and sharing critieria.
System Bandwidth Requirement	RF	25KHz
	Ground	Primary 56 Kbps , dial backup 64 Kbps ISDN
System and Channel Capacity (number of channels and channel size)	RF	Unlimited system growth - primarily dependent on regulatory frequency allocation. Ground stations are capable of four independent frequencies. Initial deployment will be based on aircraft equipage and will only require 1-2 frequencies.
	Ground	APN X.25 packet switched services and IP and ATN protocols
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Simplex - Transmission or reception on a single frequency but not simultaneously.
	Ground	Simplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	data
	Ground	data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
	Ground	The VDL Mode 2 ground network can prioritize messages over the wide area network and within the ground station in accordance with ATN priority schemes. Once presented to the radio for transmission, messages are not preempted.
Physical channel characteristics (LOS, OTH, etc.)		
	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	RTCA DO-160C, Sections 15, 18, 19, 20, and 21.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	First VDL Mode 2 usage expected in 2000 in En Route. Potentially applicable to all domestic phases of flight: Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	31.5 kbps/25KHz channel
Robustness of channel and system (resistance to interference, fading, multipath, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Design availability for Initial Operating Capability (IOC) is .9999. Higher availability will be achieved with additional ground stations and supporting network components for critical airports and applications.
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Within the VDL Mode 2 subnetwork, the probability of a lost packet is less than 10^{-7}. The subnetwork uses logical acknowledgements for packet delivery assurance. An additional end-to-end message assurance is applied to assure message delivery (all packets for a message).
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 200 nm at 30,000 feet 80 nm at 5,000 feet Coverage: Implementation will begin in 2000 with U.S. En Route and high density airports (Airspace A and B). Coverage will expand as users equip.

CHARACTERISTIC	SEGMENT	DESCRIPTION
Link and channel availability	RF	The availability of each ground station is 0.997. Ground station availability based on providing RF signal so radio and all components included. For typical applications, two ground stations will be available to achieve 0.9999 system availability.
Security/ encryption capability	RF	None at the RF level - VDL Mode 2 will support authentication and encryption of applications as planned by ATN.
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	None - system to be deployed in 2000. VDL Mode 2 is applicable to all user classes but is expected to be first implemented by air carriers and regional airlines operating in Class A airspace (above 18,000 feet) and associated Class B airspace airports.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Carrier Sense Multiple Access (CSMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	95% of messages delivered within 3.5 seconds within the VDL Mode 2 subnetwork. End-to-end delivery is estimated at 95% within 5 seconds.
Avionics versatility (applicability to other aircraft platforms)	System	VDL Mode 2 can be used for all applications.
	Avionics	VDL Mode 2 can be used on any class aircraft.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.)	Ground	Ground stations must be installed for coverage
	System	Signal in space characteristics are set by National and International standards. Avionics are developed by vendors with proprietary designs. Can share VHF equipment with other applications (VHF voice).
Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)		The digital radios used by VDL Mode 2 are capable of providing analog voice service and/or VDL Mode 3 service with appropriate software and hardware additions. Radio is dedicated to one Mode when installed.
Source documents		ARINC VDL Mode 2/ATN Briefing for FAA

5.2.3 VDL Mode 3

VDL Mode 3 is also an ATN subnetwork. VDL Mode 3 has been designed for Air Traffic controller-pilot communications for both voice and data. VDL Mode 3 uses time division to split each 25 kHz channel into four subchannels, which can be any combination of voice or data. This approach allows VDL Mode 3 to provide a traditional voice service and a data link service over a single system. Each subchannel operates at 4.8 kbps. For voice service, VDL Mode 3 includes a voice encoder/decoder (vocoder) which allows digital signals to be converted to voice. As a data channel, VDL Mode 3 can provide data service at 4.8 kbps in each data subchannel.

VDL Mode 3 is under development by the FAA as the NEXCOM program. Initially NEXCOM will provide voice service to replace the current 25 kHz, double side-band amplitude modulated (DSB-AM) voice service.

Table 5.2-3. VDL Mode 3 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**Very High Frequency Digital Link Mode 3 (VDL Mode 3)**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	Very High Frequency (VHF)
	Ground	Undetermined

CHARACTERISTIC	SEGMENT	DESCRIPTION
Frequency/ Spectrum of Operations:	RF	118-137MHz
System Bandwidth Requirement:	RF	25KHz/channel; Radios are specified for 112-137 MHz tuning range.
	Ground	Undetermined
System and Channel Capacity (number of channels and channel size):	RF	As a system, VDL Mode 3 can be used for all frequencies in the VHF aeronautical band, pending frequency sharing criteria. VDL Mode 3 is planned as the replacement for all current ATC analog voice frequencies, approximately 500 channels. Each VDL Mode 3 frequency provides four subchannels per 25KHz channel.
	Ground	Fractional T-1 interfaces indicated in draft specification.
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Simplex - Transmission or reception on a single frequency but not simultaneously, within a subchannel. Subchannels can communicate independently with TDMA scheme.
	Ground	Undetermined
Method of information delivery (voice, voice recording, data, combination, etc.):	RF	Pulse code modulated voice or data in any given subchannel
	Ground	Data, ATN-compliant network protocols
System and component redundancy requirement (1/2, 1/3, etc):	Ground	Undetermined, 1:1 is current practice.
	RF	Ground components: 1:1 is current practice Airborne: 1:2
Physical channel characteristics (LOS, OTH, etc.):	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	VDL Mode 3 will begin deployment for voice function in approximately 2005 for En Route phase of flight. Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight will be added as the system expands.
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	10,500 symbols/sec (3 bits per symbol) 31.5 Kbps/channel 4.8 Kbps/subchannel, 4 subchannels/channel
Robustness of channel and system (resistance to interference, fading, multipath, atmospheric attenuation, weather, etc.)	RF	VHF channels are susceptible to terrain multipath but relatively robust and inherently resistant to fading, atmospheric attenuation, and weather.
System integrity (probability)	System	Digital = BER of 10^{-3} for minimum, uncorrected signal BER of 10^{-6} daily average
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Voice: The PCM voice will be encoded using an 8 kHz sampling rate at a resolution of 16 bits per sample.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Range dependent on altitude: Maximum 200 nm at 30,000 feet 80 nm at 5,000 feet Coverage: Implementation will begin in 2005 with U.S. En Route. Coverage will expand to all U.S. phases of flight.
Link and channel availability	RF	Radio availability =.99999
Security/ encryption capability	RF	No encryption at RF level. Should support ATN defined encryption and authentication at application level.
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	System is in implementation. Will be available to commercial, G/A, and military aircraft

CHARACTERISTIC	SEGMENT	DESCRIPTION
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Time Division Multiple Access (TDMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	< 250 msec
	System	< 250 msec
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Ground	Ground stations required for service/coverage.
	Avionics	NEXCOM will initially be deployed in analog voice Mode to allow fielding and aircraft equipage. When switched to digital voice Mode, approximately 2006, equipage will be mandatory for high En Route.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)		Signal in space and protocols are defined by National and International standards. Ground equipment will be provided by vendors using proprietary designs. VDL data can support numerous applications.
Source documents		Implementation aspects for VDL Mode 3 system (version 2.0), VDL Circuit Mode MASPS and MOPS, Aeronautical Mobile Communications Panel (AMCP); Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; RTCA /DO-224.

5.2.4 VHF Digital Link—Broadcast (VDL-B)

VDL-B is a broadcast variation of VDL Mode 2. Currently intended for Flight Information Services, VDL-B provides weather information to suitably equipped aircraft. The broadcast approach can increase the throughput of data to the user since the protocol overhead of request/reply and confirmation is not required. Under the FAA's FIS Policy, two VHF band frequencies were provided to each of two vendors for implementation. As a condition at no cost to the user, each vendor is required to transmit a minimum set of weather products. The vendor is allowed to charge fees for additional optional products such as weather graphics. The protocols for the FIS-B systems are partially proprietary and may be specified by the vendor. The vendors are expected to use the D8PSK physical layer but the upper layers are not standardized.

VDL-B is not an ICAO SARPs recognized version of VDL. The VDL-B term has been used to describe a data link intended primarily or solely for broadcast of data one-way to aircraft. Weather and traffic information are the usual applications cited for broadcast functions. The description in this report is based on VDL Mode 2 and FIS, which is the most common usage of the term VDL-B. Other variations of VDL-B are possible since it is not an official term or definition.

Table 5.2-4. VDL Broadcast Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**VHF Data Link—Broadcast (VDL-B)**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	Very High Frequency (VHF)
	Ground	Leased telco for current implementation. VDL Mode 2 network possible in the future. Other proprietary solutions possible.
Frequency/ Spectrum of Operations		118-137MHz
System Bandwidth Requirement	RF	25KHz
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Two frequencies per vendor, Total of four frequencies.
	Ground	Leased telco.
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Broadcast
	Ground	Duplex (return needed for ground station monitor and control)
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
	Ground	VDL-B is a proposed broadcast service that provides advisory and weather information to all aircraft monitoring the channel. The information provided contributes to the safety of flight. This service is similar to Flight information services (FIS)
System and component redundancy requirement (1/2, 1/3, etc)	RF	Since FIS is an advisory service, high availability is not required and redundancy will probably not be used.
	Ground	None expected.
Physical channel characteristics (LOS, OTH, etc.)	RF	Line of sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	The FIS-B information will be available in all phases of flight if the aircraft is within range of the ground station. En Route will have the most coverage while coverage on the ground will be limited. Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	31.5 KBPS if D8PSK used 19.2 for GMSK Other data rates possible
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	RF is robust and resistant to interference, fading, multi-path, atmospheric attenuation, weather
System integrity (probability)	System	Based on non-critical service category, availability is estimated as 0.99
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Unknown
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	LOS (180 nautical miles for aircraft at 25,000 feet) 80 nm at 5,000 feet
Link and channel availability	RF	0.99
Security/ encryption capability	RF	None

CHARACTERISTIC	SEGMENT	DESCRIPTION
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Intended for G/A market but available to all users.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Differential 8 Phase Shift Keying (D8PSK) or Gaussian Mean Shift Keying (GMSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Broadcast mode has not been defined
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Unkown
	System	> 5 seconds
	Avionics	Optional
	Ground	Required for message transmission
Avionics Versatility	Avionics	If D8PSK approach used, then the radio could be used for multiple applications.
Equipage Requirements	RF	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Ground	Required for message transmission
	System	Proprietary hardware/software mix.
	Avionics	Can share VHF equipment with other applications
Source documents		None

5.2.5 Mode S

Mode S is an evolution of the traditional Secondary Surveillance Radar (SSR). For Mode S, each aircraft has a unique 24-bit address, which allows transmission selectively addressed to a single aircraft instead of broadcast to all aircraft in an antenna beam. The Mode S transponder has 56 bit registers which can be filled with airborne information such as aircraft speed, waypoint, meteorological information, and call sign. The information in the register can be sent either by an interrogation from the ground system or based on an event such as a turn. For ADS-B, equipped aircraft can exchange information without a master ground station. Although capable of sending weather and other information, the Mode S communications capability is allocated to support of its surveillance role and will consist of aircraft position and intent. ADS-B uses the Mode S downlink frequency (i.e., 1090 MHz) and link protocols to squitter (i.e., spontaneously broadcast) onboard derived data characterizing the status (current and future) of own aircraft or surface vehicle via various ADS-B extended squitter message types (e.g., State Vector [position/velocity], Mode Status [identification/type category/current intent], and On-Condition [future intent/coordination data]).

Table 5.2-5. Mode S Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**Mode S**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	
	Ground	L-Band (also known as D-Band)
Frequency/ Spectrum of Operations:		1090 MHz, +/- 1MHz

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Bandwidth Requirement:	RF	2 MHz (based on the existing Mode-S downlink)
	Ground	Leased telecommunications
System and Channel Capacity (number of channels and channel size):	RF	Single 2 MHz channel
	Ground	Leased telecommunications
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Broadcast from aircraft
	Ground	Ground stations transmit at 1030 MHz and receive at 1090 MHz. For ADS-B service, receive only stations have been proposed.
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	Surveillance function has priority over communications function
	Ground	None. The probability of successful message reception and report update are specified (see Table 3-4 of RTCA DO-242 ADS-B MASPS) depending upon the specific operational applications being supported by the ADS-B system. In this broadcast system more critical data (as determine by the operation being supported) are broadcast more frequently to improve the probability of message reception and report update.
System and component redundancy requirement (1/2, 1/3, etc):	RF	This depends on the ADS-B equipage class, its hardware implementation, and the specific operational applications being supported. The system level minimum availability requirements for equipage classes A1 through A3, for example, is 0.999. This, coupled with the minimum system level continuity of service requirement for the probability of being unavailable during an operation of no more than 2 x 10 –4 per hour of flight along with the specific availability requirements for the operation being performed (e.g., parallel approach), will determine whether equipment redundancy is needed to satisfy the operational requirement. This is expected to be part of the certification process and will be based on the intended use of the ADS-B equipment and the operational approval(s) being sought.
Physical channel characteristics (LOS, OTH, etc.):	RF	Line Of Sight (LOS)
Electromagnetic interference (EMI) / compatibility characteristics:	RF	ADS-B equipment has broad EMI requirements: transmitting and/or receiving equipment shall not compromise the operation of any co-located communication or navigation equipment (i.e., GPS, VOR, DME, ADF, LORAN) or ATCRBS and/or Mode-S transponders. Likewise, the ADS-B antenna shall be mounted such that it does not compromise the operation of any other proximate antenna.
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Operational applications supported by ADS-B have been identified across all phases of flight, except possibly pre- and post-flight.
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	1 Mbps Mode-S provides data link capability as a secondary service to surveillance. Extended length message, ELM, format provides 80 user bits per 112 bit message. A typical rate is one ELM per four seconds (RTCA DO-181)
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	The L-Band frequency is subject to fading and multi-path; Mode-S uses a 24-bit parity field and forward error detection and correction (FEDC) to help address this.

CHARACTERISTIC	SEGMENT	DESCRIPTION
System integrity (probability)	System	ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is 10^{-6} or better on a per report basis. [Note: Due to constraints imposed by the Mode-S extended squitter message length, multiple messages must typically be received before all required data elements needed to generate a particular ADS-B report are available.]
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Mode-S system performance for undetected error rate is specified to be less than one error in 10^{-7} based on 112-bit transmissions.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	Assuming LOS exists, range performance depends on traffic density and the 1090 MHz interference environment (i.e., ADS-B uses the same frequency as ATC transponder-based surveillance). In low-density environments (e.g., oceanic) range performance is typically 100+ nm, while in a high-traffic density and 1090 interference environments (e.g., LAX terminal area) the range performance is on the order of 50 to 60 nm with current receiver techniques (improved processing techniques have been identified that are expected to provide range performance to 90 nm in dense environments).
Link and channel availability	RF	100%, as ADS-B is a true broadcast system
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	TBD, since still being developed. However, a significant number of initial implementations are expected to occur in aircraft already equipped with TCASII/Mode-S transponders (commercial air transport and high-end business aircraft). This area of equipage (i.e., TCASII/Mode-S) is expected to increase as the ICAO mandate for TCASII Change 7 (called ACAS in the international community) starts to occur in 2003.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Pulse Position Modulation (PPM) Each ADS-B message consists of a four pulse preamble (0.5 microsecond pulses, with the 2nd, 3rd, and 4th pulses spaced 1.0, 3.5, and 4.5 microseconds after the 1st) followed by a data block beginning 8 microseconds after 1st preamble pulse. The data block consists of 112 one-microsecond intervals with each interval corresponding to a bit (a binary "1" if a 0.5 pulse is in the first half of the interval or a "0" if the pulse is in the second half of the interval.
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Random access; squitter transmissions are randomly distributed about their mean value between some fixed high and low limits (e.g., "one-second" squitters have a one second mean value and are randomly transmitted every 0.8 to 1.2 seconds). This done to minimize collisions on the link. When collisions do occur, the receiver uses the next available message (which in a broadcast system like ADS-B will arrive shortly) to obtain the data.
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	
	ADS-B System	ADS-B uncompensated latency must be less than 1.2 ms or 0.4 ms depending upon the uncertainty of the position data (error [95% probable]) being used to support a particular operational application. The error is categorized according to navigation uncertainty categories (NUCs) from 1 to 9, with the higher NUCs indicating more accurate position data. The 1.2 ms requirement applies to NUCs less than 8 (0.05 to 10 nm position error), while the 0.4 ms must be met for NUCs 8 or 9 (3 to 10 m error).
Avionics versatility (applicability to other aircraft platforms)	Avionics	ADS-B as defined is intended to be applicable to all aircraft category types as well as surface vehicles operating in the aircraft movement area of an airport. A range of equipage classes have been defined to accommodate the various levels of user requirements from GA to air transport.

CHARACTERISTIC	SEGMENT	DESCRIPTION
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Avionics	No mandate of the ADS-B system is planned. However, if ADS-B equipment is used to perform a particular operation (e.g., IFR), a specific ADS-B equipage class, with certain minimum performance characteristics (e.g., transmitter power), will be required.
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Ground	No mandate of the ADS-B system is planned. However, if FAA were to use ADS-B to monitor ground vehicles on the airport movement areas, all such vehicles would have to be equipped with at least a minimum (i.e., broadcast-only) ADS-B system.
	System	ADS-B uses the Mode-S architecture which is a sub-network of the ATN and is based on an open system architecture.
	Avionics	The signal in space characteristics are defined by national and international forums.
Source documents		RTCA DO-242 ADS-B MASPS, RTCA DO-181 Mode-S MOPS, draft material for 1090 MHz ADS-B MOPS

5.2.6 Universal Access Transceiver (UAT)

The Universal Access Transceiver concept is intended for distribution of surveillance and weather data. It uses a unique hybrid access method of TDMA and random access. The TDMA portion is used to transmit the traffic and weather information while the random access portion is used by aircraft to transmit their own location in conformance with the RTCA DO-242 broadcast approach. The system is experimental and currently operates on a UHF frequency of 966 MHz. The bandwidth of the system is 3 MHz and a suitable frequency assignment would be difficult. UAT has not been standardized and is not currently recognized by ICAO/ATN. The system is being evaluated in the Safe Flight 21 initiative and would become an open system architecture if developed. The UAT implementation of ADS-B functionality had as its genesis a Mitre IR&D effort to evaluate a multi-purpose broadcast data link architecture in a flight environment. Its use for ADS-B was seen as a capacity and performance driver of the link. The current evaluation system (no standard exists or is in process at this time) uses a single frequency (experimental frequency assigned), a binary FM waveform, and broadcasts with 50 W of power. The system provides for broadcast burst transmissions from ground stations and aircraft using a hybrid TDMA/random access scheme. The UAT message structure, net access scheme, and signal structure have been designed to support the RTCA DO-242 ADS-B MASPS (i.e., to transmit State Vector, Mode Status, and On-Condition messages and provide the corresponding ADS-B reports for use by operational applications). The UAT is also investigating support for other situational awareness services (e.g., TIS-B & FIS-B) through sharing of the channel resources with ADS-B.

Table 5.2-6. UAT Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**UAT**
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	UHF
Frequency/ Spectrum of Operations	System	The UAT evaluation system operates on an experimental frequency assignment of 966 MHz. [Note: This band was selected due to the availability of spectrum. However, the system is not frequency specific and could operate in any suitable spectrum.]
System Bandwidth Requirement	RF	3 MHz
	Ground	≥ 1 MHz
System and Channel Capacity (number of channels and channel size)	RF	One channel, 2 MHz
	Ground	Single 1 MB/s channel

CHARACTERISTIC	SEGMENT	DESCRIPTION
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Two part: Ground broadcasts information to aircraft, aircraft transmit position information.
	Ground System	Telco
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
System and component redundancy requirement (1/2, 1/3, etc)	Ground	None, broadcast system. The probability of successful message reception/report update are specified (see Table 3-4 of RTCA DO-242 ADS-B MASPS) depending upon the specific operational applications being supported by the ADS-B system. The more critical data (as determine by the operation being supported) have minimum requirements that broadcast more frequently to improve the probability of message reception and report update. [Note: The ground station TDMA access protocol (see access scheme description below) may have some capability for message prioritization. However, this could not be determined from the documentation available.]
	RF	This is still to be determined. It depends on the ADS-B equipage class, its hardware implementation, and the specific operational applications being supported. The system level minimum availability requirements for equipage classes A1 through A3, for example, is 0.999. This, coupled with the minimum system level continuity of service requirement for the probability of being unavailable during an operation of no more than 2 x 10^{-4} per hour of flight, along with the specific availability requirements for the operation being performed (e.g., parallel approach), will determine whether equipment redundancy is needed to satisfy the operational requirement. This is expected to be part of the certification process and will be based on the intended use of the ADS-B equipment and the operational approval(s) being sought.
Physical channel characteristics (LOS, OTH, etc.)	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics	RF	UAT is being designed for operation on a clear channel. Interference to or from off-channel systems can only be assessed once an operational frequency is identified. DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Primarily En Route but operational applications supported by ADS-B have been identified across all phases of flight, except possibly pre- and post-flight. UAT is being designed to support all ADS-B applications (as defined by DO-242)
Channel data rate (digital) and/or occupied band width (analog) requirement	RF	1 Mbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	In general, the UHF frequency is subject to fading and multipath; UAT uses a 48-bit Reed-Solomon forward error correction (FEC) code and a 24-bit cyclic redundancy code (CRC) (acts as a 24-bit parity code) to help address this.
System integrity (probability)	System	UAT will be judged according to ADS-B standards. ADS-B integrity is defined in terms of the probability of an undetected error in an ADS-B report received by an application, given that correct source data has been supplied to the ADS-B system. ADS-B system integrity is 10^{-6} or better on a per report basis. Currently, the UAT worst-case overall undetected error probability for an ADS-B message is 3.7×10^{-11}, which exceeds the minimum requirement. [Note: For UAT ADS-B messages map directly (i.e., one-to-one correspondence) to ADS-B reports (i.e., they are not segmented as they are in Mode-S ADS-B).]

CHARACTERISTIC	SEGMENT	DESCRIPTION
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Worst-case overall undetected error probability for an UAT ADS-B message is 3.7×10^{-11}
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	LOS. Similar to VHF: 200 nm at 30,000 feet, 80 nm at 5,000 feet. The UAT proposal is to establish a series of ground stations to provide coverage over the U.S. at low (5,000 feet) altitude.
Link and channel availability	RF	Estimated at 0.99 since it will be an advisory service.
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	None. This is a new system design that is not implemented. It currently has appeal and support from the GA community who perceive it to be a lower cost and possibly improved performance alternative to other ADS-B candidate systems (i.e., Mode-S and VDL Mode 4). However, frequency allocation, product development, and standardization/certification of a final design will have to occur before the validity of this perception can be determined.
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	UAT uses both TDMA and Binary Continuous Phase Frequency Shift Keying in its signal cycle. The TDMA signal is used by the ground station for broadcast uplink. The Binary portion is used by aircraft to report position.
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	UAT uses multiple access techniques: time division multiple access (TDMA) in the first portion (e.g., 188 ms) of a one second “frame” (i.e., slots to separate ground station messages from the aircraft and surface vehicle messages) and random access in the second portion (e.g., 812 ms) of the frame for ADS-B messages from aircraft and surface vehicles.
Avionics versatility (applicability to other aircraft platforms)	RF	UAT is being designed to meet ADS-B requirements. ADS-B uncompensated latency must be less than 1.2 ms or 0.4 ms depending upon the uncertainty of the position data (error [95% probable]) being used to support a particular operational application. The error is categorized according to navigation uncertainty categories (NUCs) from 1 to 9, with the higher NUCs indicating more accurate position data. The 1.2 ms requirement applies to NUCs less than 8 (i.e., 0.05 to 10 nm position error), while the 0.4 ms must be met for NUCs 8 or 9 (i.e., 3 to 10 nm error).
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	RF	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares comm link with applications, etc.)	Avionics	UAT is a new system design being developed from scratch to meet ADS-B requirements. Therefore, since ADS-B as defined is intended to be applicable to all aircraft category types as well as surface vehicles operating in the aircraft movement area of an airport, UAT should be expected to have the avionics versatility needed to address the set of ADS-B requirements. A range of ADS-B equipage classes have been defined to accommodate the various levels of user requirements from GA to air transport
	Ground	Design information available to all vendors
	System	UAT is a new system and currently does have any standards (e.g., RTCA MOPS or ICAO SARPS).
Source documents	UAT	UAT system information was obtained from various briefings to RTCA SC-186 Plenary meetings and private Mitre correspondence. The system description is largely for an evaluation system involved in the current Safe Flight 21 tests and can be expected to change.

5.2.7 Example Geosynchronous (GEO) Satellites (Recommended SATCOM)

Limited aviation communications are currently available via satellite. The InMarSat GEO satellite provides voice and low-speed data service to aircraft in the oceanic domain. The data service has been used to supplement HF voice air traffic control. Satellite voice for air traffic has been limited to emergency voice. The satellite services are installed on aircraft for commercial passenger voice service and the air traffic control services are provided as a secondary consideration. In an emergency, the pilot has priority access to the communication channel. The large dish size used for GEO satellites is expensive and difficult to install on smaller aircraft such as GA. Cargo aircraft do not have the passenger voice communications support and therefore, have not traditionally been equipped with satellite communications equipment.

The InMarSat-4 (Horizons) satellites are proposed for 2001. Due to the crowded spectrum in L-band, Horizons may be deployed at S-band. Data rates of 144 kbps with an Aero-I aircraft terminal and 384 kbps with an Aero-H terminal are forecast. The Horizons satellites may have 150-200 spot beams and 15-20 wide area beams.

5.2.7.1 InMarSat-3

Table 5.2-7. InMarSat-3 Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		Inmarsat-3
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	SATCOM – GEO satellite. Five satellites.
	Ground	Ground Earth Stations (GES)
Frequency/ Spectrum of Operations:		C Band ~ 4,000 to 8,000 MHz, and L Band ~1,000 to 2,000 MHz
System Bandwidth Requirement	RF	2.5, 5.0, 7.5, AND 17.5 KHZ
	Ground	N/A
System and Channel Capacity (number of channels and channel size)	RF	Six channels per aircraft for Aero H
	Ground	
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	RF	Simplex
	Ground	Half Duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	Avionics	Digitally encoded voice
	Ground	Digitally encoded voice
Data/message priority capability / designation (high, intermediate, low, etc.)	RF	None
	Ground	None
System and component redundancy requirement (1/2, 1/3, etc):	RF	Two ground stations per region; one satellite per region; Some aircraft may have redundant avionics
	Ground	Two ground stations per region
Physical channel characteristics (LOS, OTH, etc.):	RF	Geosynchronous Satellite, ~ 1/3 earth footprint
Electromagnetic interference (EMI) / compatibility characteristics	RF	N/A

CHARACTERISTIC	SEGMENT	DESCRIPTION
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Pre-flight, departure surface operations, terminal, en-route/cruise, landing, and post flight
Channel data rate (digital) and/or occupied band width (analog) requirement:		Voice: 20 kbps; Data: Aero-H: 9.6 kbps; Aero-I: 4.8 kbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Highly robust
System integrity (probability)	System	No integrity requirement for 2007 data services.
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Voice is toll quality.
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	RF	1/3 Earth Regional: Indian Ocean, Pacific Ocean, East Atlantic and West Atlantic regions overlap and cover the entire earth within +/- 85 degrees latitude.
Link and channel availability	RF	Satellite operates within the 10 MHz band assigned to AMS (R) S for satellite service by ICAO.
Security/ encryption capability	RF	N/A
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Commercial aircraft
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	Aeronautical-Quadriture Phase Shift Key (A-QPSK), Aeronautical variation of QPSK
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Voice: Time Division Multiplexing (TDM) to aircraft; Time Division Multiplexing Access (TDMA) from aircraft. Data: Frequency Division Multiplexing Access (FDMA)
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Satellite signal propagation delay
	System	End to end delay within acceptable limits for voice transmission
Avionics versatility (applicability to other aircraft platforms)	Avionics	Size and weight of Avionics and antenna are prohibitive for small GA aircraft. Aero-I may fit in some business jet GA a/c
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	Optional
	Ground	Ground Earth Stations (GES) required for receipt of satellite signals
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary hardware and software
	Avionics	Independent data link
Source documents		InMarSat SDM; Nera System Summary; InMarSat fact sheets; Annex 10, Aeronautical Telecommunications, International Civil Aviation Association (ICAO); ARINC Market Survey for Aeronautical Data Link Services

5.2.7.2 Potential GEO Satellites

Other GEO satellites have been proposed that are potentially applicable to the aviation market and which are described further in the Task 9 report. They include the AMSC/TMI satellites, Loral Skynet, CyberStar and Orion satellites, the ASC and AceS systems and the proposed Celestri combination GEO/LEO satellite system. They are not discussed further in this report due to their limited service offering or due to their limited remaining satellite life expectancy. Many details of proposed satellites are unavailable either because they are proprietary developments or the designs are still in development. A representative 2007 GEO system based on the LM/TRW Astrolink and Hughes Spaceway systems is presented below.

Table 5.2-8. GEO Satellite Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		LM/TRW Astrolink GEO, Hughes Spaceway GEO. (At least one of these or a similar system should be operational in 2007)
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	Ka-band
	Ground	Unknown
Frequency/ Spectrum of Operations:	RF	Ka-band, 20 GHz downlink from satellite, 30 GHz uplink to satellite
System Bandwidth Requirement:	RF	500 MHz or more, each direction, maybe split 4 or 7 ways for frequency reuse in each cell (spot beam)
	Ground	
System and Channel Capacity (number of channels and channel size):	RF	16kbps to 2Mbps standard channels, hundreds of channels available. Over 100Mbps gateway or hub channels.
	Ground	Unknown
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	duplex, may be asymmetric
	Ground	Duplex
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	Multiple priorities available
	Ground	Unknown
System and component redundancy requirement (1/2, 1/3, etc):	RF	Design life of 10 to 15 years, high system availability (0.9999 goal)
	Ground	Unknown, typically multiple ground stations in view
Physical channel characteristics (LOS, OTH, etc.):	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	possible interference from terrestrial Ka-band systems (LMDS, fiber alternatives systems), regulated through spectrum licensing
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	All
Channel data rate (digital) and/or occupied band width (analog) requirement:		FDM/TDMA burst (packet) channels, variable bit rates, 1 to 100+ Mbps

CHARACTERISTIC	SEGMENT	DESCRIPTION
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	variable rate coding and variable data rates to mitigate deep rain fades, many frequencies available to avoid fixed interference
System integrity (probability)	System	0.9999 availability typical goal
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	10^{-9} or better typical
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	RF	global possible, but most systems do not intend to cover oceans and polar regions, GEO systems point spot beams to land masses and high population areas in particular
Link and channel availability	RF	0.9999 availability typical goal
Security/ encryption capability	RF	terminal authentication during access encryption can be overlaid, but not a basic feature
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Fixed ground terminal service beginning in 2003
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	digital, QPSK, burst (packets), FEC variable rates 1/2 or higher
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	FDM/TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	latency: approx. 0.3 second for GEO
	System	
Avionics versatility (applicability to other aircraft platforms)		Not designed for fast moving terminals, can be achieved if business is identified and the developer designs capability.
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	optional
	Ground	
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
	Avionics	Independent
Source documents		FCC and ITU spectrum license applications, conference publications

5.2.7.3 MEO Satellites

MEO satellite systems have been proposed for the Aeronautical Mobile Service. MEO systems have several advantages over the GEO and LEO approaches. The reduced transmission distance of MEO systems provides a higher link margin. Compared to LEO systems, the MEO satellites are in view to an individual aircraft longer and experience less frequent handoffs. Boeing, ICO-Global, Celestri, and Teledesic are possible MEO satellites for the 2007 timeframe. The following table is based on the ICO-Global system. (Note: Segment is used only for characteristic with multiple descriptions)

Table 5.2-9. ICO Global Satellite Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		**ICO Global**
Communications/link type (HF, VHF, L-Band, SATCOM, other):		SATCOM MEO satellites; 10 satellites in two planes of 5 each (plus 2 spares)
Frequency/ Spectrum of Operations:	Service Band, Uplink	2.170 – 2.200 GHz
	Service Band, Downlink	1.98 – 2.010 GHz
	Feeder Band, Uplink	6.725 – 7.025 GHz
	Feeder Band, Downlink	5 GHz (AMS(R)S)
	Crosslink Band	N/A
System Bandwidth Requirement:	System	Unknown
System and Channel Capacity (number of channels and channel size):	RF	24,000 circuits total/4.8 Kbps voice
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Duplex
Method of information delivery (voice, voice recording, data, combination, etc.):	RF	GSM Voice
Data/message priority capability / designation (high, intermediate, low, etc.):	System	None
System and component redundancy requirement (1/2, 1/3, etc):	RF	10 satellites in two planes of 5 each (plus 2 spares)
Physical channel characteristics (LOS, OTH, etc.):	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics:	RF	Service Link Margin 8.5 dB, DO-160D for avionics
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	All
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	4.8 Kbps voice
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Moderate. Max one-satellite duration: 120 minutes Connectivity characteristics: Simultaneous fixed view required
System integrity (probability)	System	Not stated
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Unknown
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight	System	Full earth coverage
Link and channel availability	RF	Not stated
Security/ encryption capability	System	Not stated

CHARACTERISTIC	SEGMENT	DESCRIPTION
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	RF	None
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	QPSK
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	TDMA (implied that path diversity and combining will be used
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Latency: ~140ms path + sat switching + 100ms in 2 codecs
Avionics versatility (applicability to other aircraft platforms)	RF	No avionics available.
Equipage requirements (mandatory for IFR, optional, primary, backup)	RF	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
Source documents		ARINC Satellite Study

5.2.7.4 LEO Satellites

The IRIDIUM system is shown in the following template to represent potential LEO systems although IRIDIUM has gone bankrupt and will not be available. The 66 satellite IRIDIUM LEO system was designed for mobile voice and low-speed data and has been proposed for aeronautical mobile users. FCC filings have indicated future IRIDIUM versions would provide higher speed data services. In addition to the low data rate, LEO systems must overcome the frequent handoff problem that occurs as a satellite transits the user location.

Table 5.2-10. IRIDIUM Satellite Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name		**Iridium**
Communications/link type (HF, VHF, L-Band, SATCOM, other)	RF	SATCOM; LEO satellites; 66 satellites in 6 planes of 11 each (plus 12 spares)
Frequency/ Spectrum of Operations	Service Band, Uplink	1.62135 – 1.62650 GHz (AMS(R)S)
	Service Band, Downlink	1.62135 – 1.62650 GHz (AMS(R)S)
	Feeder Band, Uplink	29 GHz
	Feeder Band, Downlink	19 GHz
	Crosslink Band	23 GHz

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Bandwidth Requirement	System	10.5 MHz
	Channel	31.5 kHz/50 kbps/12 users
System and Channel Capacity (number of channels and channel size)	RF	3840 circuits/sat; 56,000 circuits total
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.)	System	duplex
Method of information delivery (voice, voice recording, data, combination, etc.)	System	Voice and data
Data/message priority capability / designation (high, intermediate, low, etc.)	System	None
System and component redundancy requirement (1/2, 1/3, etc)	RF	66 satellites in 6 planes of 11 each (plus 12 spares)
	Ground	Satellite-satellite switching for high ground system availability
Physical channel characteristics (LOS, OTH, etc.)	RF	LOS
Electromagnetic interference (EMI) / compatibility characteristics	RF	Service link margin: 16.5 dB no combining min BER 10^{-2} DO 160D for avionics
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	Ground	All
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	2.4 Kbps and 4.8 Kbps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	High. Max one-satellite duration: 9 minutes Connectivity characteristics: Flex to any station at any location
System integrity (probability)	RF	$1x10^{-6}$
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	Compressed voice, toll quality
Range/ Coverage/ footprint (oceanic, global, regional / line-of-sight	System	Full earth coverage
Link and channel availability	RF	99.5%
Security/ encryption capability	System	Proprietary protocol
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	RF	No aviation usage
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	QPSK, FEC rate _,
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	FDMA/TDMA

CHARACTERISTIC	SEGMENT	DESCRIPTION
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	12 ms path; 175 ms total
Avionics versatility (applicability to other aircraft platforms)	RF	No avionics available
Equipage requirements (mandatory for IFR, optional, primary, backup)	Avionics	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications)	System	Proprietary
Source documents		ARINC Satellite Study

5.2.8 High-Frequency Data Link

HF data link provides an alternative to oceanic satellite data and HF voice communications. The aircraft changes are small, consisting primarily of a radio upgrade and a new message display capability. HF antenna and aircraft wiring can remain the same. HFDL is cheaper to install and operate than satellite. For cargo aircraft that do not need the passenger voice service of satellite, HFDL provides a cost effective data link. HFDL is adaptive to radio propagation and interference. It seeks the ground station with the best signal and adjusts the data-signaling rate to reduce errors caused by interference. HFDL service is faster, less error prone and more available than traditional HF voice communications. HFDL has not yet been approved for carrying air traffic messages and aircraft equipage is just beginning.

Table 5.2-11. HFDL Characteristics

CHARACTERISTIC	SEGMENT	DESCRIPTION
System Name:		HIGH FREQUENCY DATA LINK (HFDL) (GLOBAlink/HF)
Communications/link type (HF, VHF, L-Band, SATCOM, other):	RF	High Frequency (HF)
	Ground	ARINC Data Network System (ADNS) & ARINC Packet Network (APN)
Frequency/ Spectrum of Operations:		2.8 MHz to 22 MHz
System Bandwidth Requirement:	RF	3 kHz Single Side band, carrier frequency plus 1440 Hz. Each Station provides 2 channels
	Ground	N/A
System and Channel Capacity (number of channels and channel size):	RF	Two channels per ground station
	Ground	ADNS & APN X.25 packet switched services
Direction of Communications (simplex, broadcast, half-duplex, duplex, asymmetric, etc.):	RF	Half-duplex
	Ground	Full duplex with a separate channel for each transmit and receive path, however the communications equipment often blocks receive voice when the operator is transmitting resulting in a half-duplex operation.
Method of information delivery (voice, voice recording, data, combination, etc.):	Avionics	Data
	Ground	Data

CHARACTERISTIC	SEGMENT	DESCRIPTION
Data/message priority capability / designation (high, intermediate, low, etc.):	RF	N/A
	Ground	A ground based priority and preemption capability that enables Air Traffic Services (ATS) messages to be delivered ahead of Aeronautical Operational Control (AOC) messages. A higher priority single or multiblock ATS message will be serviced before lower priority multiblock messages. The transmission of lower priority multiblock messages will resume when the higher priority message is completed. Lower priority messages will be delivered in their entirety to the aircraft. Lower priority single-block messages are not preempted due to protocol and avionics implementation requirements. The immediate preemption by higher priority messages of lower priority multiblock messages is also supported.
System and Component Redundancy	RF	HFDL Ground Stations (HGS) are geographically located to provide a 1 / 2 equipment diversification with each site transmitting two frequencies to provide a 1 / 4 relationship for radio frequencies.
	Ground	ETE availability for HFDL through ADNS and APN provides redundancy with an availability of 1.00000. In the North Atlantic Region redundancy is also provided with an equipment availability of.99451 for the passport backbone Access Module. In the Pacific Region total redundancy is provided ETE.
Physical channel characteristics (LOS, OTH, etc.):	RF	Via ionosphere
Electromagnetic interference (EMI) / compatibility characteristics:	RF	DO-160D
Phase of Flight Operations (Pre-flight, departure surface operations, terminal, en route/cruise, landing, post-flight, combination)	System	Pre-flight, departure surface operations, terminal, en route/cruise, landing, and post-flight
Channel data rate (digital) and/or occupied band width (analog) requirement:	RF	Adaptable to propagation conditions: 1800, 1200, 600, 300 bps
Robustness of channel and system (resistance to interference, fading, multi-path, atmospheric attenuation, weather, etc.)	RF	Signals in the HF band are influenced by the characteristics inherent in transmitting through the ionosphere, which include various emissions from the sun interacting with the earth's magnetic field, ionosphere changes, and the 11-year sunspot cycle which affects frequency propagation. HF is also affected by other unpredictable solar events. Frequency management techniques are used to mitigate these effects
System integrity (probability)	System	No integrity requirement for 2007 data services, Forward error detection
Quality of Service Performance (via BER for digital, voice/qualitative (synthetic, toll grade, etc.)	System	95% of uplink message blocks in 60 seconds (one-way); 95% of uplink message blocks in 75 seconds (round-trip); 99% of uplink message blocks in 180 seconds (round-trip
Range/ Coverage / footprint (oceanic, global, regional / line-of-sight, etc.)	RF	3,000 nm from each ground station. Ten stations deployed as of December 1999 with 3-4 more sites under consideration to complete Global coverage.
Link and channel availability	RF	≥99.8% End to End Operational Availability
Security/ encryption capability	RF	None
Degree / level of host penetration or utilization (transport only, G/A only, combination of hosts, % penetration, etc.)	System	Commercial aircraft, 50-100 equipped. New service with potential 8,000 users

CHARACTERISTIC	SEGMENT	DESCRIPTION
Modulation scheme (analog/digital, AM, FM, PSK, etc.)	RF	M-Phase Shift Keying (M-PSK) 1800 (8-PSK); 1200(4-PSK); 600 (2-PSK); 300 (2-PSK)
Access Scheme (CSMA, TDMA, SCPC, FDMA, CDMA/spread spectrum, hybrid, etc.)	RF	Slotted TDMA
Timeliness/latency, delay requirements (real-time, end-end delay, minimal acceptable time delivery envelope, etc.)	RF	Uplink end-to-end: 2 minutes/95%, 6 minutes/99% of messages Downlinks end-to-end: 1 minute/95%, 3 minutes/99%
Avionics versatility (applicability to other aircraft platforms)	Avionics	Any aircraft equipped with HF transmit and receive equipment and the appropriate HFDL interface unit
Equipage requirements (mandatory for IFR, optional, primary, backup, etc.)	Avionics	Optional
Architecture requirements (OSA/open system architecture, proprietary hardware/software, mix, etc.) Level of integration with other aircraft avionics (independent data link, shares communications link with applications, etc.)	System	Signal in space defined by national and international standards. HF Voice equipment may be shared with other HF applications (i.e., HF voice).
Source documents		Annex 10, AERONAUTICAL TELECOMMUNICATIONS, ICAO; ARINC Quality Management Reports, Air/Ground Voice Performance; ARINC specification 635-2 ARINC Aeronautical Data Link Proposal, 1997; HFDL Ground Station System Segment Specification

5.3 Link Considerations

5.3.1 Ground based systems

All aviation communications systems based on ground stations have limitations of coverage and range. The majority of aviation communications systems are line of sight limited. The radio frequency power available permits operation at distances up to 200 nautical miles (nm). However, the curvature of the earth blocks the signal to aircraft unless the aircraft is at high altitude. At low altitudes such as 5,000 feet, the line of sight range is reduced to approximately 30 nm. Mountains also block signals and reduce potential coverage. Satellites are much less limited in coverage but do become constrained by available power. A geosynchronous satellite can cover one-third of the earth but the radio frequency power will be far less than for terrestrial systems. Traditionally satellite systems have used dish antennas to increase received power. Newer satellite concepts include low earth orbit (LEO) and medium earth orbit (MEO) systems which are closer to the earth which improves the available power while reducing the coverage for each satellite.

5.3.2 Frequency band

The aviation industry has traditionally used frequency spectrum allocated specifically to aviation applications and protected by national and international law from interference. Under international agreement, the aviation communications frequencies are limited to ATC and AOC use. Services such as entertainment and passenger communications have been prohibited. All of the VHF systems, voice

DSB-AM, ACARS, VDL Mode 2, Mode 3, and Mode 4 are designed to operate within the current 25 kHz channel spacing of the 118 - 137 MHz protected VHF band.

Three major configurations of satellite systems were considered. GEO systems depend on satellites in geosynchronous orbit. Usually a single satellite provides wide area coverage that is essentially constant. Coverage is not possible at the poles. MEO satellites move relative to the earth and their coverage shifts. A number of satellites are needed and earth coverage is virtually complete. A failure of a single satellite causes a short-term outage. LEO satellites move quickly relative to the earth and require numerous satellites for full earth coverage; therefore, an outage of a single satellite is short-term.

5.3.3 General Satellite Comments

Ka and extremely high frequency (EHF) systems are best for fixed or slowly moving terminals, not for aviation speed terminals (path delay variation, Doppler, frequent hand-off between spot beams). Coding and other link margin features may be used to compensate for speed when the aircraft is above atmospheric degradation (rain). The GEO and MEO systems avoid oceans by not pointing spot beams there (systems with phased array antennas will be capable of pointing at oceans) and LEO systems plan to power down the satellites while over the oceans or low population areas. These issues are not technological problems; they are design choices based on business cases. To insure capability for aeronautic use, economic opportunity needs to be communicated to the system developers (business cases supporting premium charges, particularly over unpopulated areas).

Alternatives to these systems will likely be provided by established service providers, such as Inamoratas (at Ku-band, and possibly new systems at Ka-band), and Boeing, which is aggressively pursuing multimedia to the passenger with asymmetrical return link. There will be a premium charge for this type system relative to fixed-ground terminals, particularly when outside of populated areas.

Boeing has already demonstrated direct video broadcast (DVB) standard communication to the aircraft. The emerging DVB-RCS (return channel satellite) standard will probably be capable of asymmetric communication with aircraft and be available in 2007.

5.3.4 Summary of Links

The communications links are summarized in Table 5.3-1, which presents the key performance characteristics. The most significant consideration in our review has been the need to provide high bandwidth and capacity. As shown, existing and near term links are limited in bandwidth and capacity and will be unable to meet the future traffic load from FIS and TIS. Message latency is also a significant consideration, especially for the ATC critical message types. Considerations such as modulation scheme, frequency, integrity, range and protocol are important design considerations buy are not the major factors for selecting a future data link.

Table 5.3-1. Capacity Provided by Various Communication Links

Data Link	Single Channel Data Rate	Capacity for Aeronautical Communications	Channels Available to Aircraft	# Aircraft Sharing Channel (Expected Maximum)	Comments
	kbps	Channels	Channels	Aircraft	
HFDL	1.8	2	1	50	Intended for Oceanic
ACARS	2.4	10	1	25	ACARS should be in decline as users transition to VDL Mode 2

Data Link	Single Channel Data Rate	Capacity for Aeronautical Communications	Channels Available to Aircraft	# Aircraft Sharing Channel (Expected Maximum)	Comments
VDL Mode 2	31.5	4+	1	150	System can expand indefinitely as user demand grows
VDL Mode 3	31.5*	~300	1	60	Assumes NEXCOM will deploy to all phases of flight
VDL Mode 4	19.2	1-2	1	500	Intended for surveillance
VDL – B	31.5	2	1	Broadcast	Intended for FIS
Mode-S	1000**	1	1	500	Intended for surveillance
UAT	1000	1	1	500	Intended for surveillance/FIS
SATCOM	-	-	-	-	Assumes satellites past service life
Future SATCOM	384	15	1	~200	Planned future satellite
Future Ka Satellite	2,000	~50	~50	~200	Estimated capability - assumes capacity split for satellite beams
Fourth Generation Satellite	>100,000	>100	>100	Unknown	Based on frequency license filings

* Channel split between voice and data.

** The Mode-S data link is limited to a secondary, non-interference basis with the surveillance function and has a capacity of 300 bps per aircraft in track per sensor (RTCA/DO-237).

Appendix A. Acronyms

AAC	Airlines administrative communications
AATT	Advanced Air Transportation Technologies
ACARS	aircraft communications addressing and reporting system
ADAS	AWOS data acquisition system
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast
AFSS	automated flight service station
AM	amplitude modulation
AMS	acquisition management system
AMS(R)S	Aeronautical Mobile Satellite (Route) Service
AOC	airline operations center
ARTCC	Air route traffic control center
ASIST	Aeronautics Safety Investment Strategy Team
ASOS	automated surface observing system
ASR-9	airport surveillance radar- nine
ASR-WSP	airport surveillance radar- weather system processor
ATCSCC	Air traffic Control System Command Center
ATIS	Automatic Terminal Information Service
ATM	air traffic management
ATN	Aeronautical Telecommunication Network
ATS	air traffic services
ATSP	air traffic service provider
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
AWOS	automated weather observing system
CD	compact disk
CONOPS	concept of operations
CONUS	Continental United States
CP	conflict probe
CPU	central processing unit
CSA	communications system architecture
CTAS	Center-TRACON Automation system
DA	descent advisor
DAG-TM	Distributed Air/Ground Traffic Management

DoD	Department of Defense
DOT	Department of Transportation
DOTS	dynamic ocean tracking system
DSR	Display System Replacement
FAA	Federal Aviation Administration
FANS 1/A	future air navigation system
FAR	Federal Aviation Regulation
FBWTG	FAA bulk weather telecommunications gateway
FCC	Federal Communications Commission
FDM	flight data management
FDP	flight data processor
FFP1	Free Flight Phase 1
FIS	Flight Information Service
FL	flight level
FP	flight plan
FSS	flight service station
GA	general aviation
GPS	Global Positioning System
GWS	graphical weather service
HARS	high altitude route system
HF	high frequency
IF	interface
IFR	Instrument flight rules
IMC	instrument meteorological conditions
IOC	initial operating capability
ITWS	Integrated terminal weather system
LLWAS	Low-level wind shear alert system
MDCRS	Meteorological Data Collection and Reporting System
METAR	meteorological aviation report
MOPS	minimum operational performance standards
NAS	National Airspace System
NAS RD	NAS Requirements Document
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NESDIS	national environmental satellite, data, and information service
NEXRAD	next generation radar

NLDN	national lightning detection network
NWS	National Weather Service
NWS/OSO	National Weather Service/Office of Systems Operations
OASIS	operational and supportability implementation system
OAT	Office of Advanced Technology
ODAPS	oceanic display and planning system
PFAST	passive final approach spacing tool
PIREPS	pilot reports
RA	resolution advisory
RD	requirements document
RTCA	RTCA, Incorporated
RTO	Research Task Order
RVR	runway visual range
TAF	Terminal Aerodrome Forecast
TBD	to be determined
TDWR	terminal Doppler weather radar
TFM	traffic flow management
TM	traffic management
TMS	traffic management system
TRM	Technical Reference Model
TWIP	terminal weather information for pilots
VDL	very high frequency digital link
VFR	visual flight rules
VHF	very high frequency
WARP	weather and radar processor
WMSCR	weather message switching center replacement
WJHTC	William J. Hughes Technical Center
WxAP	weather accident prevention